ASTRONOMY

JULY 1977

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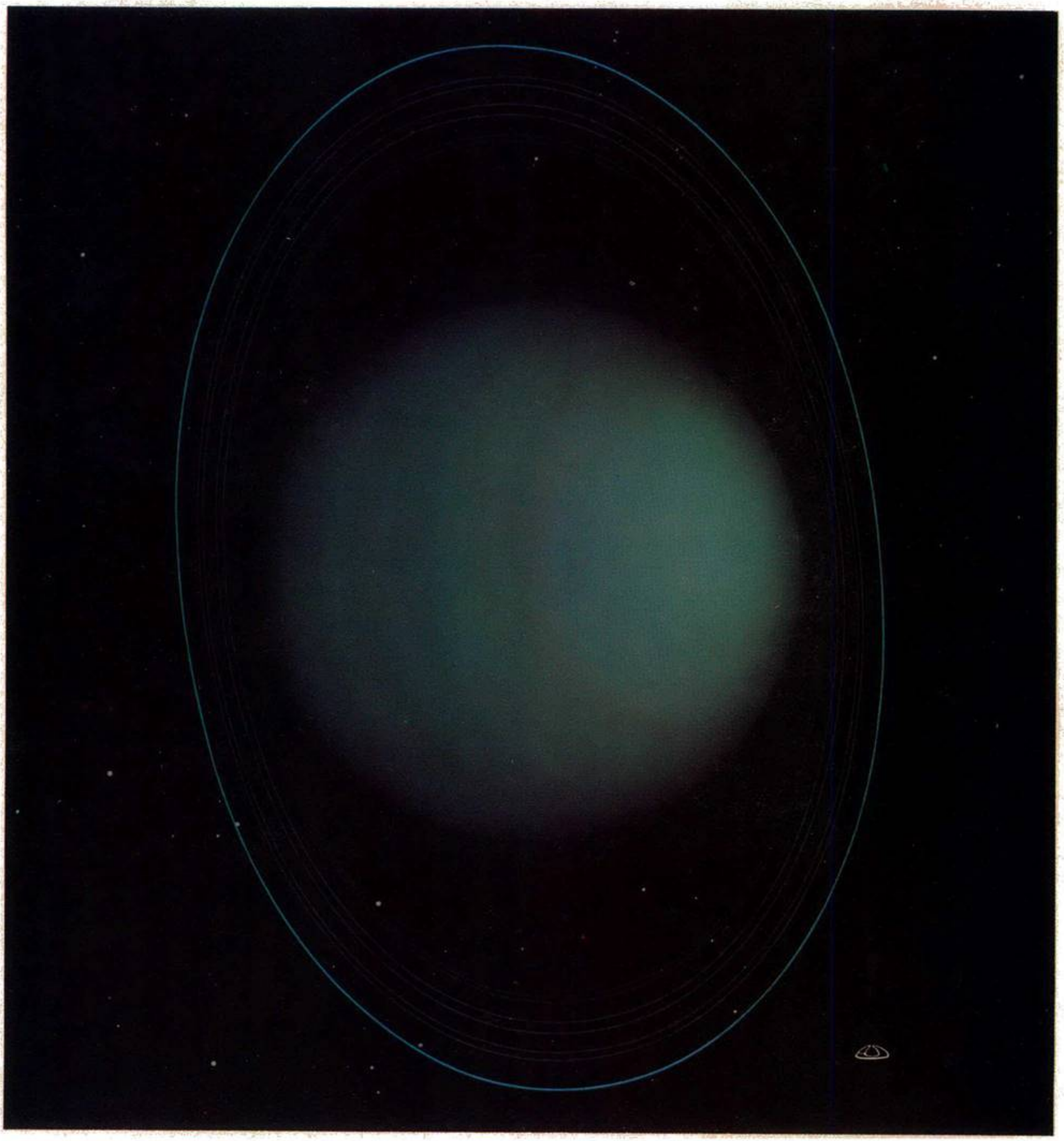
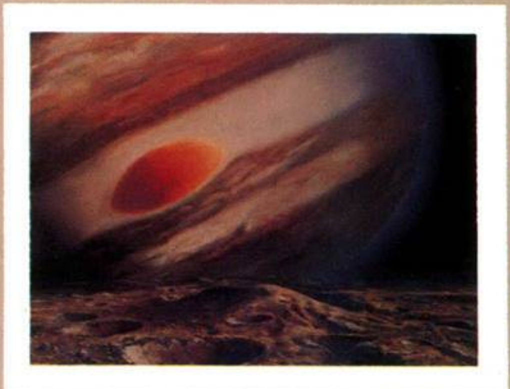


NEW FROM

To you, our readers, ASTRONOMY now offers a series of 8 dynamic, new, full color Art Reprints of some of the best paintings — by artists John Clark, Victor Costanzo, James Hervat, Mark Paternostro, Adolf Schaller and Rick Sternbach — that have appeared in ASTRONOMY Magazine.

Adding to the drama, depth and realism of each piece, these Art Reprints are printed on 80 lb. linen finish paper, and are coated with a high gloss varnish. And each reprint is surrounded with a one inch white border,



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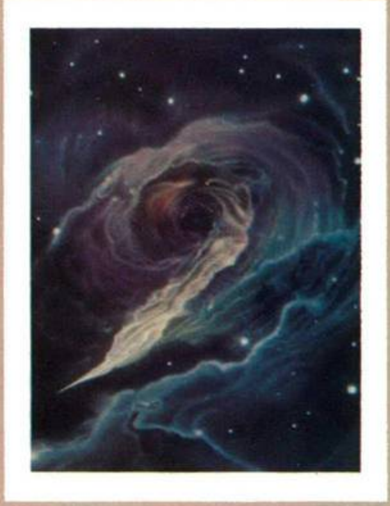
Jupiter From Io

This dramatic painting reveals an incredible vista that man may never witness first hand: the incredible bulk of Jupiter looming over the surface of its satellite Io. Located deep within Jupiter's intense magnetic field, Io is one of the most lethal places in the entire solar system. To view this scene, we must rely on the imagination of artist John Clark.



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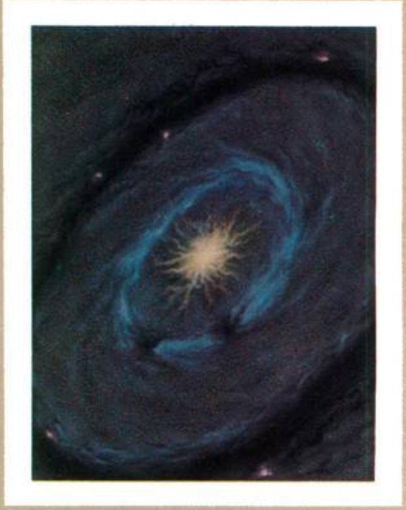
Black Hole

A nearly invisible small black hole speeds through a dense interstellar cloud of gas and dust, leaving behind a trail of gravitationally disturbed material. The infalling material becomes hot and emits light as it drains out of the known universe. Artist Mark Paternostro speculates on the appearance of these still undetected objects.



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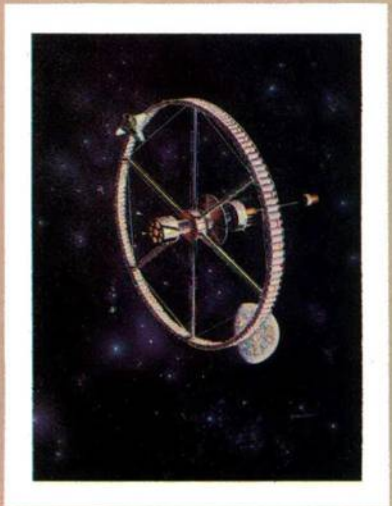
The Galactic Core

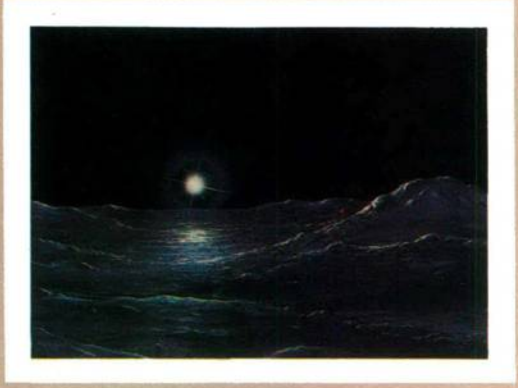
The nucleus of our galaxy is one of the true unknowns in our universe. Recent radio and infrared observations suggest that two titanic swirling rings of gas and dust occupy the core of our galaxy. These rings were apparently produced by an explosion 10 million years ago. Victor Costanzo's painting indicates that actual conditions at the galaxy's center remain a mystery.



Actual Size: 17 x 22

Colony in Space

What will space stations and orbiting colonies of the future look like? Artist Rick Sternbach provides an ingenious answer in his painting of a mile wide space station wheeling slowly above the gibbous Earth. Shuttle rockets near the station's hub bring ore from the lunar surface for refinement in the station's zero gravity manufacturing center.



Actual Size 17 x 22

Pluto

The setting sun glints off a low plain of methane ice on the surface of the smallest and most distant planet, Pluto. The cold and forbidding scene — completely alien to Earth dwellers — comes to life in this rendition by James Hervat. The mysteries of Pluto are brought home to us as we stand and gaze back toward our incredibly distant sun.

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making it easier to frame, or suitable for hanging as is.

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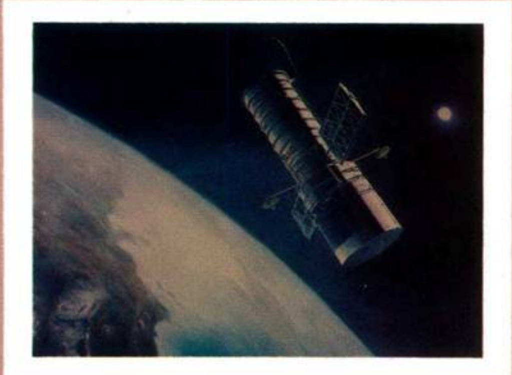
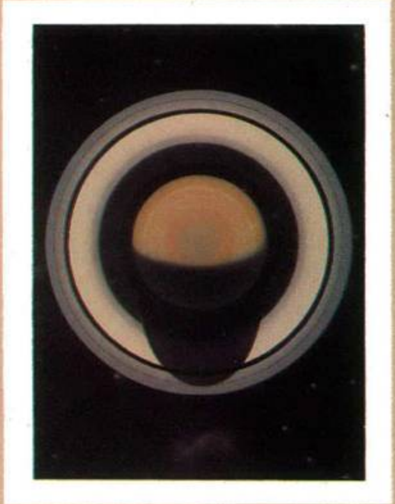


Actual Size: 17 x 22

Space Telescope

Painted by John Clark from official NASA blueprints, this poster depicts the Space Telescope — a powerful 94 inch (2.4 meter) aperture telescope due to be launched during the early 1980s by NASA's Space Shuttle. This is an accurate depiction of an instrument that will revolutionize man's view of the universe during the decades it remains in operation.



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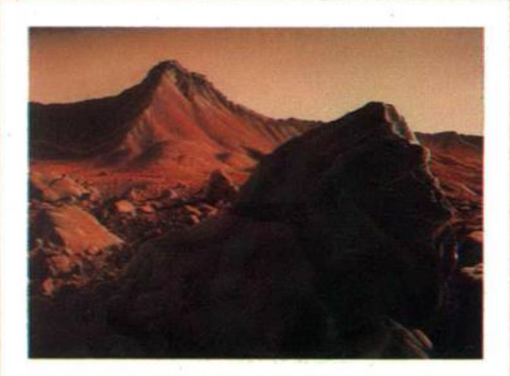
Saturn

In an unusual perspective from above the north pole of Saturn, we can identify the planet's three main rings and their sizes relative to Saturn itself, enabling us to grasp the vast extent of Saturn's ring system. This remarkable painting by Adolf Schaller gives us a view of the planet not obtainable from Earth.

Vallis Marineris

Photographs returned from Mariner and Viking probes revealed for the first time the immensity of Vallis Marineris, the equatorial canyon of Mars. This painting by Adolf Schaller — meticulously transcribed from overhead Viking photos — takes us to the foot of a blanket of landslide rubble in the canyon itself.



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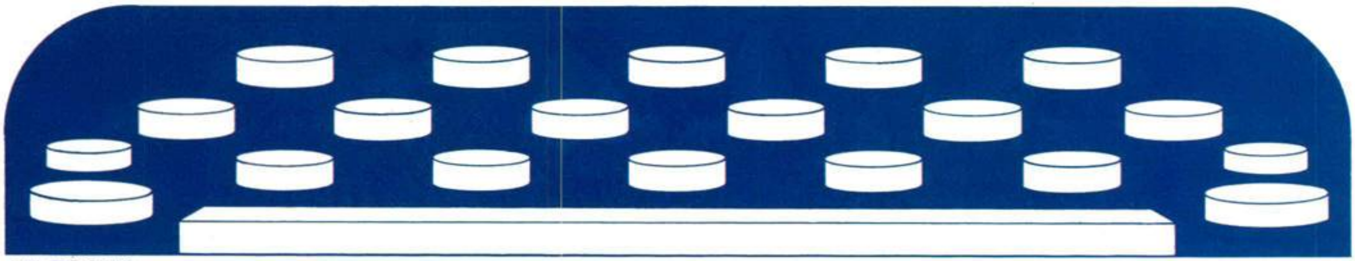

IN FOCUS

Sir / In "Can Life Evolve in Elliptical Galaxies?" (May 1977), John Gribbin claims that elliptical galaxies cannot contain life bearing planets because there has been no recycling of the heavy elements synthesized by first generation stars out of hydrogen and helium into second and subsequent generations.

Giant elliptical galaxies, particularly their cores, are observed to contain stars whose spectra show bands due to CN (the cyanogen molecule) as strong or stronger than solar neighborhood stars of the same surface temperatures. This implies surface abundances of carbon and nitrogen at least as large as those in the sun. Nitrogen is a secondary nucleus; that is, it cannot be made in a single generation of stars starting with pure hydrogen and helium. It can only be made (through CNO cycle burning of hydrogen) by stars which begin their lives with significant amounts of carbon and oxygen — in Gribbin's terminology, in second generation stars. Thus, the presence of CN-rich stars in elliptical galaxies shows that material has been recycled through more than one generation of stars in them. The hypothesis that ellipticals cannot have life bearing planets because there are no stars made out of material containing heavy elements therefore breaks down on comparison with observations. This is, of course, fatal to a hypothesis! The relevant observations are freely available in technical literature. The pioneering work was that of McClure and Van den Bergh [**Astronomical Journal** (1968)] . Many more recent studies are cited in a review by Audouze and Tinsley [**Annual Review of Astronomy and Astrophysics** (1967)] .

DR. VIRGINIA TRIMBLE
University of California, Irvine

Dr. Trimble / The point raised emphasizes the confusion of nomenclature that has arisen concerning different kinds of stars in our own and other galaxies. The convention is to divide these into two groups, Population I (young) and Population II (old); but, in fact, the division is not entirely clearcut, which is why I used the deliberately vaguer expressions "first generation" and "second generation". Whichever way you look at it, ellipticals do contain mainly Type II and older Type I stars, while spirals contain both these and younger Type I specimens. [Nonscientist students of astronomy can check this in such standard texts as Robert Dixon's **Dynamic Astronomy** *(1971).]*

Such galaxies are indeed free from gas and dust, presumably because in the absence of rotation, it has all fallen into the central region. [The most succinct description of the process is given by I.S. Shklovskii and Carl Sagan in their book, **Intelligent Life in the Universe** *(1966).] Of course, that residual gas may have become enriched somewhat in the meantime. Maybe I should have introduced a new category of 1-1/2 generation stars!*

In spite of this semantic confusion, however, the main thrust of my argument remains. Solar systems like our own, with planets like Earth harboring life as we know it, now seem to be very much the product of spiral structure in the galaxy. And, giving credit where credit is due, the essential new features of the work I described were not the result of my own efforts, but those of Prof. W.H. McCrea.

One swallow doesn't make a summer, and a few CN enriched stars are not the same as a Population I disk.

DR. JOHN GRIBBIN
Brighton, Sussex, England

Editor's Note: John Gribbin's arguments work well enough for dwarf elliptical galaxies, but as Dr. Trimble points out, giant ellipticals do contain a significant number of "second generation" stars. The more massive giant elliptical galaxies apparently underwent star formation, evolution and supernova dispersion during the formation of the galaxy itself; thus, they began with a second generation heavy element abundance, and presumably could have had life bearing planets for the entire life of the galaxy. However, with a few exceptions, there doesn't seem to be much star formation in giant ellipticals now.

The heavy elements in the cores of elliptical galaxies have only been found in the last decade. Popular accounts and textbooks being written today will incorporate these new findings, but older sources such as the books Dr. Gribbin mentions are out-of-date in this field.

Much recent work has shown that our early ideas about galactic evolution were much too simple. Our understanding increases each year.

Sir / I would like to comment on Barry Parker's article, "The End of Time" (May 1977). Parker speculates that in future universes, the fundamental constants may be different than ours; given this, he further speculates on the possibility of life evolving in these future universes. He seems to conclude that since "life in our universe is 'finely tuned' to the fundamental constants it now has", life will be unable to evolve in "some (possibly most)" of these future universes. In particular, given a universe lasting only a few million years, he concludes that such a universe could not have life.

Basically, what Parker has done is to allow the universe another degree of freedom (the altered constants), but in the next moment he refuses to allow the evolution of life the same extra degree of freedom. Since the universal constants have been altered, who can have any conception of what the requirements for life are? You've changed the rules of the game, but life must play by the old rules. This seems unjustifiably restrictive.

Surely, in a new universe, life would evolve to fit the new universal constants — if that universe were one in which molecules and atoms could form at all. But that life would surely be different from our universe's life. It is unreasonable to expect such a basic change not to have an effect on the life that evolves.

Admittedly, this is all pure conjecture, but if one is to speculate, I prefer to do so optimistically rather than pessimistically. In the case of a universe of short lifespan, the constants may be such as to allow living things to evolve relatively faster, with the result that *every* "star" would have "life" on its "planets".

BRUCE BRYSON
Goleta, Calif.

Mr. Bryson / You have raised a very interesting point. We'd like to throw this question out to our readership: What are the limitations — or possibilities — for the evolution of life in diverse environments, not only in our universe, but in other universes?

Ooops!

Here are a few errors that appeared in the June issue:

Page 29 — the bottom telescope diagram was mislabeled Folding Reflector; it should have been labeled Folded Refractor.

Page 34 — the third paragraph (sixth line) in the right column should read "Longitude is given in horizontal divisions beginning with zero degrees at the Greenwich Meridian and increasing to 180 degrees."

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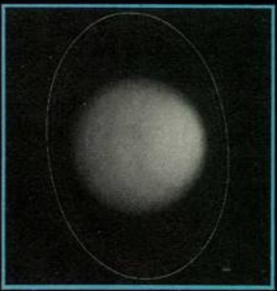

Cover

Uranus' rings, now thought to be seven in number, circle the chilly planet's equator at an average distance of 29,000 miles (46,000km). Unlike the well-known Saturnian ring system, Uranus' rings are very slender bands of dust separated by wide gaps. Saturn's rings are broad, separated by narrow gaps. In this issue, ASTRONOMY shows you the exciting x-ray universe and strange collapsed objects (white dwarfs, neutron stars and black holes) that emit x-rays, and introduces you to the growing new field of x-ray astronomy. You'll see how x-ray discoveries are rapidly revising the textbooks of the last decade. Photography in Astronomy shows you beautiful pictures you can take with telephoto lenses you may already own, and Gazer's Gazette shows you how to track an asteroid. Artwork by Adolf Schaller.

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THE X-RAY

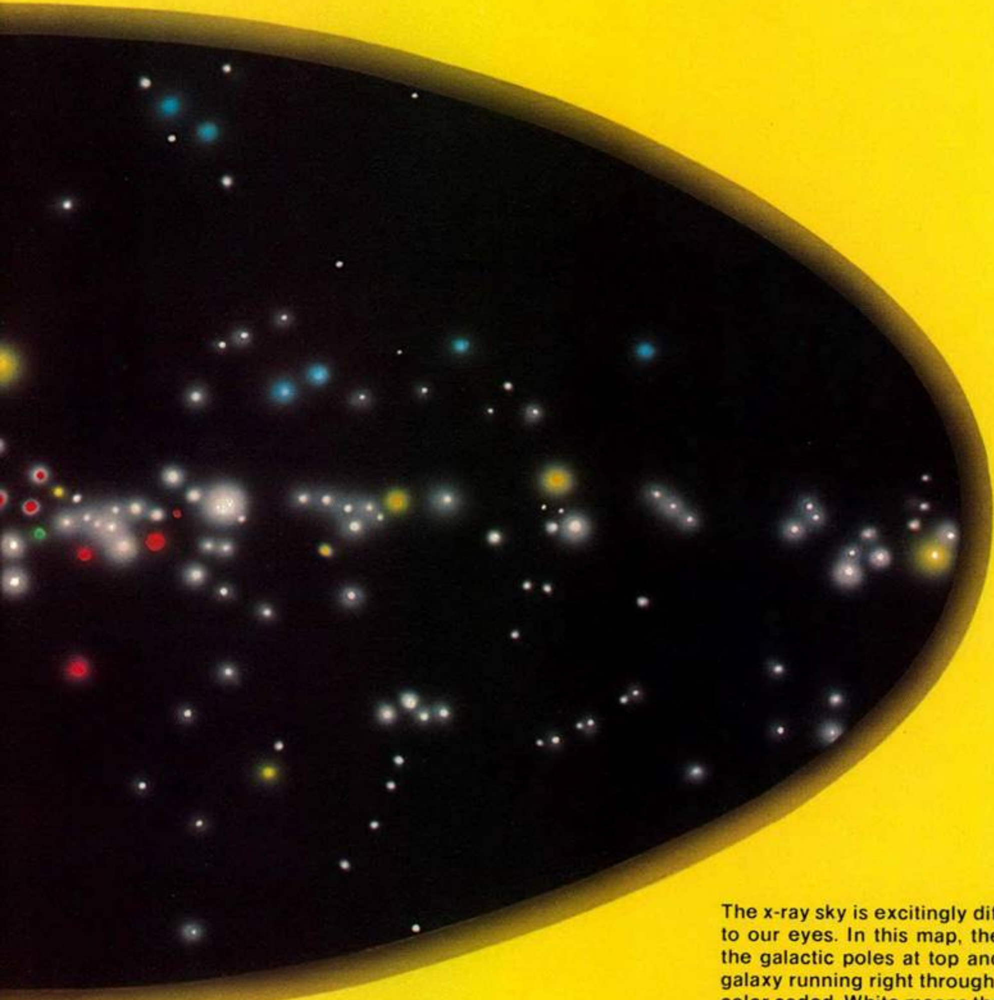
by

Thomas Markert and Thomas L. Pencek

As the 1950s were the years of radio astronomy, and the 1960s the years of quasars and pulsars, so the 1970s are the years of x-ray astronomy. The x-ray universe has produced some of the most exciting astronomical discoveries of this decade.

There is, of course, nothing intrinsically exciting about x-rays in space. But the implications of the x-rays' existence, the unusual and exotic properties of their sources, and the strange story they tell of the collapse of stars into bizarre "compact objects" have captured our imaginations. There are many stars and other objects, for example, that emit 10,000 or more times as much energy in x-rays than they do *at all other wavelengths* combined. Such a huge flux of high energy radiation forces scientists to consider the existence either of enormous volumes of hot gas, intense magnetic fields, or vast numbers of high energy particles — or combinations of these phenomena. At least on the large scales demanded by the observations, these things simply don't exist in ordinary stellar systems. In order to explain the very existence of space x-rays, theorists have had to employ many of the unusual and energetic objects in the astrophysical "zoo", such as neutron stars, black holes and supernovae. It is

UNIVERSE



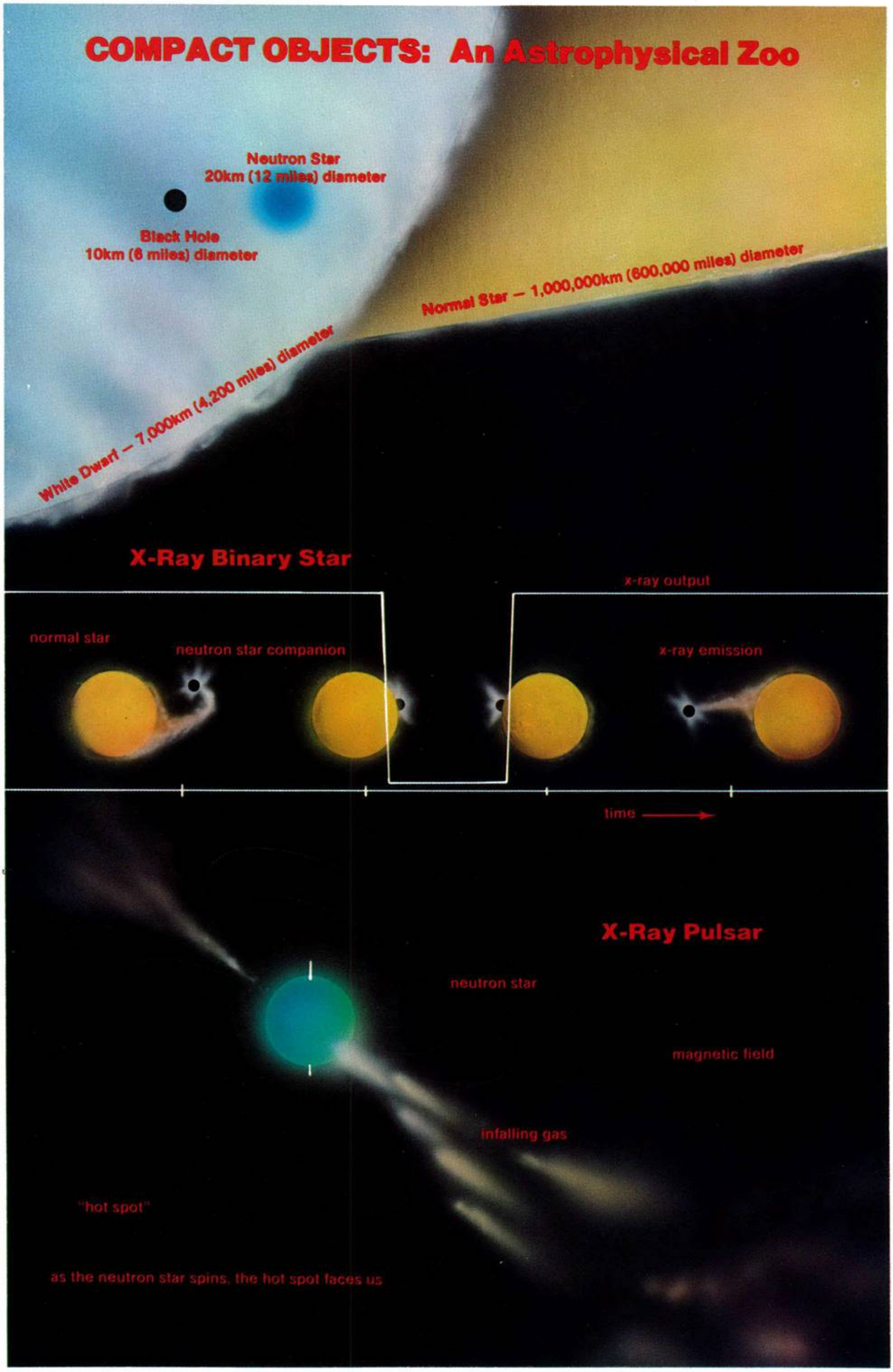
The x-ray sky is excitingly different from the familiar sky visible to our eyes. In this map, the galactic center is in the middle, the galactic poles at top and bottom, with the equator of the galaxy running right through the middle. The x-ray sources are color coded. White means the source's optical or radio counterpart is unknown or unidentified; red means the source is a burster — it flares up suddenly every few days or hours; yellow means the source is a binary star system; green indicates globular clusters (unless they are globular cluster bursters); blue shows sources outside our galaxy, such as other galaxies, clusters of galaxies and quasars. Map information courtesy of the Uhuru Group at the Smithsonian Astrophysical Observatory. Artwork by Mark Paternostro.

this combination of fascination with the universe, complex and demanding observations, and exotic theoretical explanations that has aroused great interest in the new field of x-ray astronomy.

Astronomical x-ray observations could not begin until the space age. Because x-rays cannot penetrate the atmosphere, observations must be carried out on rockets, satellites or giant balloons. Solar x-rays were first observed in 1948 and, since the sun is so close, they could be measured with relatively crude detectors. Solar observations accounted for the bulk of x-ray observations until the early 1960s.

X-ray astronomy outside of our solar system

COMPACT OBJECTS: An Astrophysical Zoo


Neutron Star
20km (12 miles) diameter
Black Hole
10km (6 miles) diameter
Normal Star — 1,000,000km (600,000 miles) diameter
White Dwarf — 7,000km (4,200 miles) diameter
X-Ray Binary Star
x-ray output
normal star
neutron star companion
x-ray emission
time
X-Ray Pulsar
neutron star
magnetic field
infalling gas
"hot spot"
as the neutron star spins, the hot spot faces us

"began" almost accidentally in 1962. A group of industrial scientists from Cambridge, Mass. were planning to test some x-ray detectors by studying the moon. While the short-term goal of their experiment was to detect solar x-rays fluoresced from the lunar surface, their long-term goal was to develop x-ray instrumentation to the point where they could hope to detect some of the very faint x-ray sources they were convinced existed in space.

They mounted their detectors on a sounding rocket (a small rocket which could spend only a few minutes above the atmosphere), from which measurements of x-rays from the moon or elsewhere could be made. The flight was successful, although no lunar x-rays were observed. Instead, the equipment detected a large flux of x-rays from the rough direction of our galaxy's center. All reasonable estimates seemed to indicate that the object emitted x-rays at a level 1,000 times greater than the total energy output of the sun! Nothing like it had ever been predicted.

The initial excitement of this fascinating discovery led many scientists — all hoping to understand this new phenomenon — into the field. Early experiments were relatively crude: Only short trips above the atmosphere were possible; the x-ray collecting area of the detectors was small, and it was impossible to determine the direction of the x-ray flux to better than a few degrees. Within a few years, however, rocket and balloon observations had detected a few dozen discrete sources of x-rays — some of which were identified with well-known objects such as the Crab nebula.

Although these early observations helped establish x-ray astronomy as an independent and fascinating branch of astronomy, it was not until satellite observations began that a comprehensive body of x-ray data was assembled. The satellite era began in 1970 with the launch of NASA's first Small Astronomy Satellite. The spacecraft, christened Uhuru, proved a tremendous improvement over previous x-ray instruments. In fact, on Uhuru's first Earth orbit, the amount of data available to scientists doubled; man's total knowledge about stellar x-rays grew daily.

A normal star, white dwarf, neutron star, and black hole are shown side-by-side, and the amazing thing is that all of them have the same mass! White dwarfs are 1,000,000 times more compressed than our sun; neutron stars are 100,000,000 times denser than a white dwarf. At these incredible densities, matter no longer behaves like it does at human scale densities. More amazing still are black holes, so dense that light itself cannot escape.

Some x-ray binary stars produce vital clues about their nature because they are eclipsing binaries in which the x-ray source star passes behind the other as it orbits. When x-ray astronomers see a sharp periodic cutoff in the x-ray source, they learn that the source of the x-rays must be small — not large as another normal star would be and, therefore, one of the compact objects!

An x-ray pulsar is powered by infalling gas channeled by a neutron star's magnetic field. The gas falls with terrific force on a tiny x-ray "hot" spot on the neutron star's surface. As the neutron star spins, we receive a periodic pulse of x-rays. Artwork by Mark Paternostro.

Compact Objects and X-Rays

Why do compact objects seem to play a special role as x-ray sources? Basically, the intense gravity at the surfaces of these objects provides an environment in which extremely high temperatures can be attained. The surface gravity of a neutron star, for example, is over 10^{13} times as great as Earth's. When matter falls onto such a star, its energy is converted to heat — in some cases enough heat to produce thermal x-rays.

For these theoretical reasons, x-ray sources have long been suspected of being compact objects. It has always been difficult, however, to prove that any of the x-ray sources which were discovered were, in fact, collapsed stars — primarily because of the problem of detecting compact objects at wavelengths other than x-ray. They are so small that they generally give off very little light and have to be characterized in some way other than by an optical identification.

Uhuru (and a few other satellites launched shortly after) revolutionized x-ray astronomy. They provided a list of nearly 200 x-ray sources, made the first discoveries of x-ray binary stars, x-ray pulsars, x-ray emission from globular star clusters and clusters of galaxies, and supplied some of the crucial evidence that led to the first tentative identification of a black hole.

Now, 15 years after the beginning of x-ray astronomy and seven years after satellite observations of x-rays began, the discipline is maturing. A complete body of data is available, and it's finally possible to make general statements about the x-ray sky as a whole, rather than recite findings about a few individual objects. Just imagine the confusion — and excitement — if the sky in visible light had first been seen by humans only 15 years ago!

The X-Ray Sky

Where do extraterrestrial x-rays come from? Probably the best answer to this question is "everywhere". Virtually every star, including the sun, is at least a faint x-ray emitter. The sun is so close to Earth that, even though it's a relatively weak x-ray source intrinsically, it is by far the brightest x-ray object in the sky. If the sun were as far away as the next nearest star, its x-rays would be barely detectable to the most sensitive instruments now in orbit.

Some of the brightest sources of x-rays are as far away as the center of our galaxy — about 30,000 light-years distant. Nearly all the bright x-ray sources lie within 10 degrees of the plane of our galaxy. Unlike visible stars which dot the sky evenly, only a few bright x-ray objects can be found very far from the galactic plane.

Many of the weaker x-ray sources are believed to be objects lying far outside our galaxy. Here again the contrast between optical and x-ray skies

X-Rays From Pulsars

There are now nine known objects that emit x-rays in regularly spaced pulses, with periods ranging from 0.7 second to 14 minutes. The simplest way known to produce pulsed x-rays is by the rotation of a magnetized collapsed object. The star must be compact in order to spin with a short period. It must be magnetized for it to have special directions on its surface (its magnetic poles) that can be swept into the field of view of the observer during every rotation period. It is from the magnetic poles that x-ray emission actually occurs.

Most scientists agree that x-ray pulsars are neutron stars. If we assume that the x-ray pulsar is a rotating, collapsed star, then it is fairly easy to argue that it must be a neutron star. As a collapsed star it is either a neutron star, white dwarf, or black hole. White dwarfs are collapsed stars of relatively small mass and density and have relatively large radii of about 6,000 miles (10,000km). Such large objects would probably be flung apart if forced to undergo the rapid rotation required of a fast x-ray pulsar. Black holes can be excluded as pulsars because these objects have no magnetic fields; hence, they can have no characteristic features which can rotate into and out of the field of view to produce pulses.

The only remaining candidate for an x-ray pulsar, therefore, is a neutron star. These are more massive than white dwarfs and less massive than black holes. After they exhaust their thermonuclear fuel, they collapse to the point where they become a giant atomic nucleus, composed almost entirely of neutrons. It is the nuclear repulsion that keeps the neutrons separated and prevents further collapse. Neutron stars ordinarily have masses somewhat greater than the sun's, but occupy a sphere only about six miles (10km) in radius.

is marked: Only two or three nearby galaxies can be seen with the unaided eye, but x-ray detectors have found dozens of extragalactic sources — some more than 100 million light-years away.

X-ray sources are now identified with all sorts of astronomical phenomena — on every scale of size and strangeness — beginning with black holes, neutron stars, white dwarfs and flare stars; continuing through ordinary stars (like our sun), giant stars, supernova remnants, globular clusters; to galaxies of various kinds, and finally to quasars and entire clusters of galaxies.

Compact Objects: X-Ray Emitters

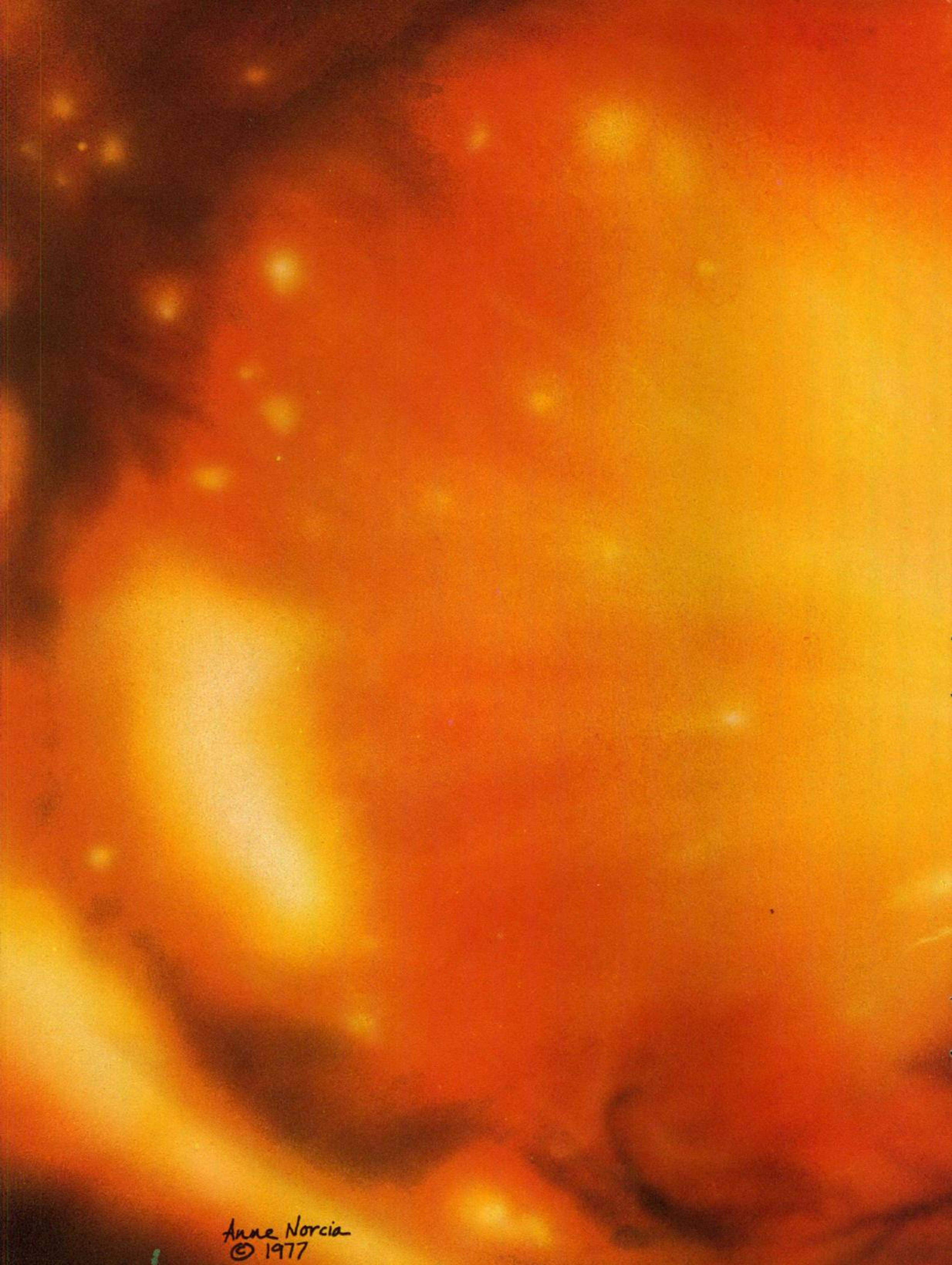
Many x-ray sources are compact objects — objects that have masses equal to or greater than the sun, but occupying volumes smaller than Earth. These objects (sometimes called collapsed stars) are stars that have exhausted their nuclear fuels and are no longer able to support themselves. White dwarfs, neutron stars, and black holes are all members of this unique family.

Two properties of several of the x-ray sources in our galaxy provided important clues which led to identification of the "compact" nature of many galactic sources. The first was the discovery of several x-ray sources in double star or binary systems. X-ray observations from the satellites revealed that some of the sources underwent regular and sharp eclipses every few days. If the position of the sources was accurately measured, often a prominent (fairly bright), more or less normal star was right where the x-ray source was observed. In every case, the normal star did not have a visible companion when viewed through a telescope; it seemed likely that the x-ray source — which was being eclipsed — was a very faint object. Furthermore, in order for the x-ray source to eclipse so sharply, it has to be very small; otherwise, the eclipse would be gradual, as more and more of the x-ray emitter slipped behind the primary star (see the diagram on page 8). The simplest interpretation of these facts (particularly in light of the convenient manner in which compact objects could produce x-rays) was that the object being eclipsed was a collapsed star.

Finding binary x-ray sources not only helped establish that compact objects were the source of the x-rays, but also explained where the matter to fuel the sources came from. An atom falling into a neutron star releases a great deal of energy upon impact. It is necessary, nevertheless, for a great many atoms to fall in order to produce a flux of x-rays bright enough to be easily detected halfway across the galaxy! While a collapsed star alone in space has no sufficient source of matter (there just isn't enough gas spread between the stars), a binary stellar system can provide the necessary mass. If the primary star emits a stream of gas — similar in nature but more intense than our sun's solar wind — some of this may be collected by the collapsed object. As the gas falls in, it emits x-rays. Alternatively, the two stars may simply be so close together that part of the atmosphere of the normal star is pulled off by the gravity of the collapsed star onto its surface, thus emitting x-rays. Both processes take place among the collection of binary x-ray sources we now observe in our galaxy.

Falling onto a neutron star's surface, gas from the accretion disk is heated to "x-ray hot" as powerful magnetic fields compress it as it falls, and as kinetic energy is released when it hits the surface. At some 1,200 miles (2,000km) above the neutron star, the hot gas, stripped of its electrons, begins to form giant "raindrop" blobs under the influence of its intense magnetic field. As the gas falls, it stretches into thin ribbons of ultraheated plasma — atoms ripped apart — emitting x-rays. You are a mere half mile (one kilometer) above the neutron star as you watch this matter in its violent, but magnificent, fall. Artwork by Ernest Norcia.

E. Norcia © 1977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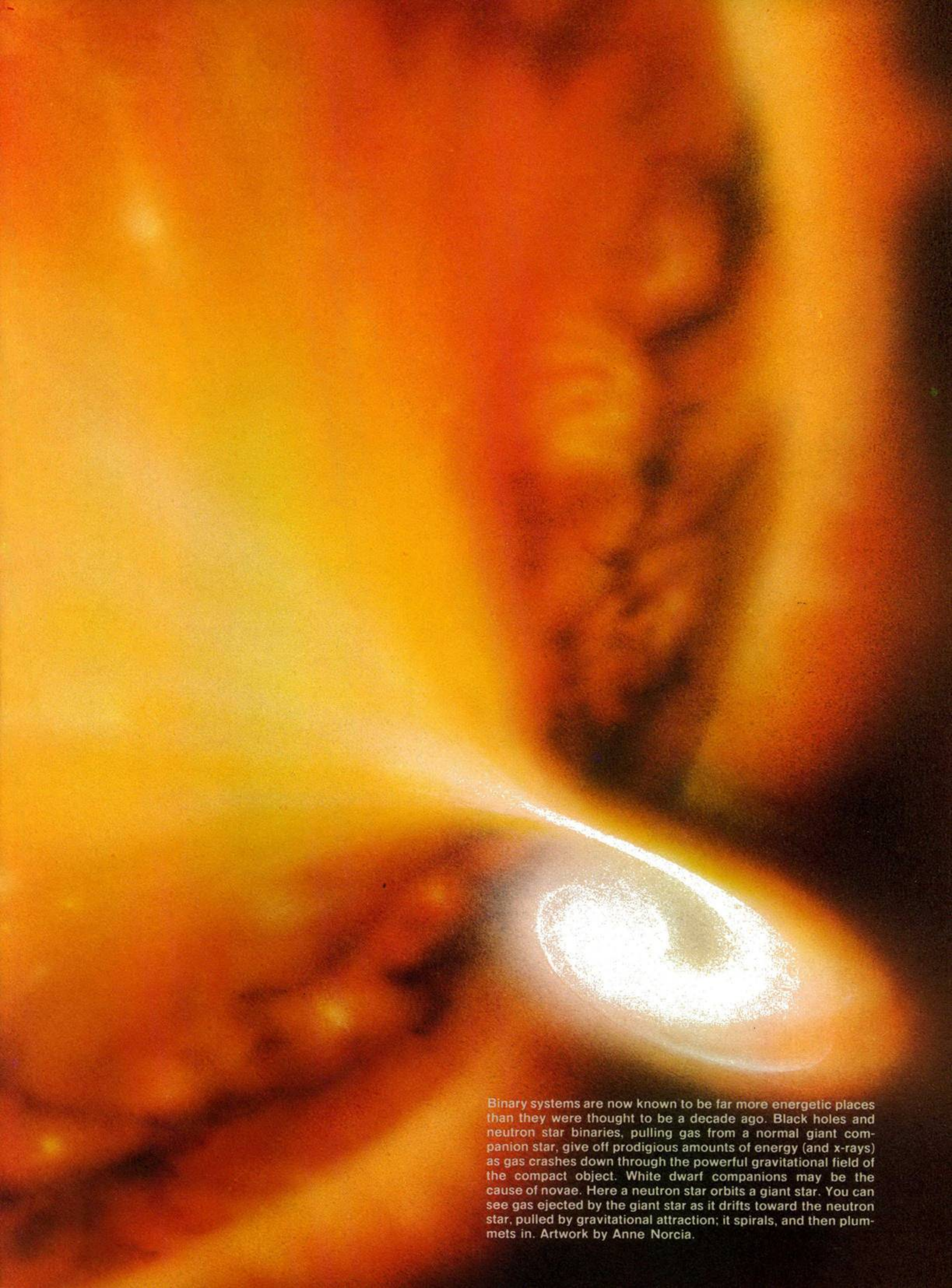
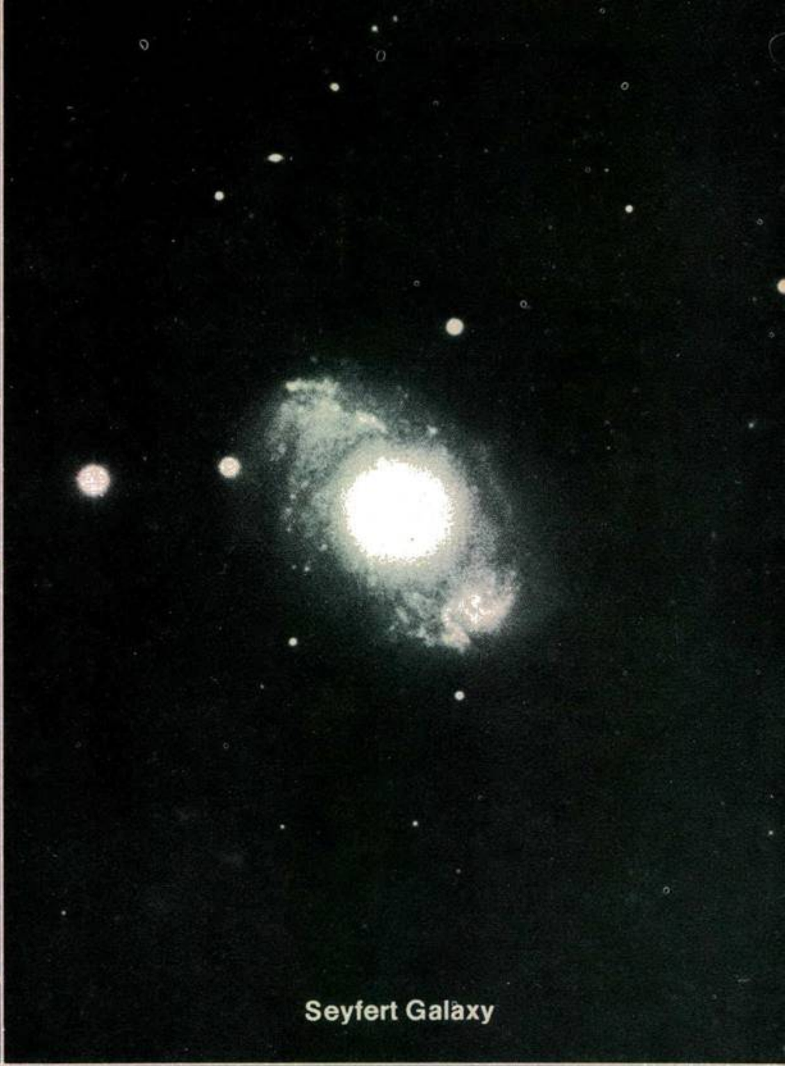


Binary systems are now known to be far more energetic places than they were thought to be a decade ago. Black holes and neutron star binaries, pulling gas from a normal giant companion star, give off prodigious amounts of energy (and x-rays) as gas crashes down through the powerful gravitational field of the compact object. White dwarf companions may be the cause of novae. Here a neutron star orbits a giant star. You can see gas ejected by the giant star as it drifts toward the neutron star, pulled by gravitational attraction; it spirals, and then plummets in. Artwork by Anne Norcia.

Globular Cluster



Seyfert Galaxy

Cluster of Galaxies

Radio Galaxy

The Mystery of Cygnus X-1

The detective work which led to the identification of Cygnus X-1 with a black hole is fascinating. It is difficult to demonstrate directly that an x-ray source is a black hole, but it is usually sufficient to show that the source is too massive to be either a white dwarf or neutron star and thus, must be a black hole.

For Cygnus X-1, this demonstration began by finding the optical companion to the x-ray emitting object. This was not an easy task since even the best x-ray detectors had rather poor angular resolution. In spite of this drawback, by 1971 there was only one prominent object (a massive blue supergiant star) within the area of positional uncertainty of the x-ray source. Radio astronomers made extremely precise measurements of the region, and found a radio emitting object in the same place as the supergiant. Furthermore, in 1971, the x-ray and radio sources underwent simultaneous variations in intensity, indicating that the x-ray and radio sources were (almost certainly) identical. Since the positional agreement had already demonstrated that the radio and optical sources were the same, the identification of Cygnus X-1 with a system containing the blue supergiant was established.

Careful observations of the blue star's Doppler shift indicated, as expected, that it was a member of a binary system. Although no eclipses were observed, the shifting of the supergiant's spectral lines indicated that it was a binary with a 5.6 day period. (The lack of any eclipse could be explained if the orbital plane of the system were sufficiently inclined to the line of sight.) Spectroscopic observations also yielded the velocity of the supergiant and an estimate of its mass. Combined with a limit on the orbital inclination, these observations set a lower bound on the mass of the compact object: about 3.7 solar masses. In theory (although the theory is not unchallenged), the maximum mass for a neutron star is 3.2 solar masses. Therefore, by elimination, Cygnus X-1 must be a black hole.

The train of logic establishing Cygnus X-1 as a black hole can — and is — being debated. Nevertheless, because of the many difficult observations that must be made and because black holes are quite rare, there is no other object for which such a strong case can be made. X-ray astronomy has thus been crucial in the search for black holes.

In the picture commonly accepted by astrophysicists today, matter from the more-or-less ordinary companion star flows into the vicinity of the compact object. It is heated to a plasma: Electrons are stripped off their atoms, and the gas consists of charged particles. Near the neutron star these particles feel the force of its intense magnetic field. They respond by moving along the magnetic field, finally plummeting onto the neutron star's magnetic poles, where x-rays are produced. Like Earth, the magnetic poles are not in the same place as the poles of rotation, so as the neutron star spins, the x-radiating magnetic poles are periodically brought into and out of view. When x-ray pulsars were discovered, the link between compact stars and x-ray emissions became stronger. Pulsars are the neutron star remnant of a supernova explosion (see "Supernovae!", ASTRONOMY, April 1977).

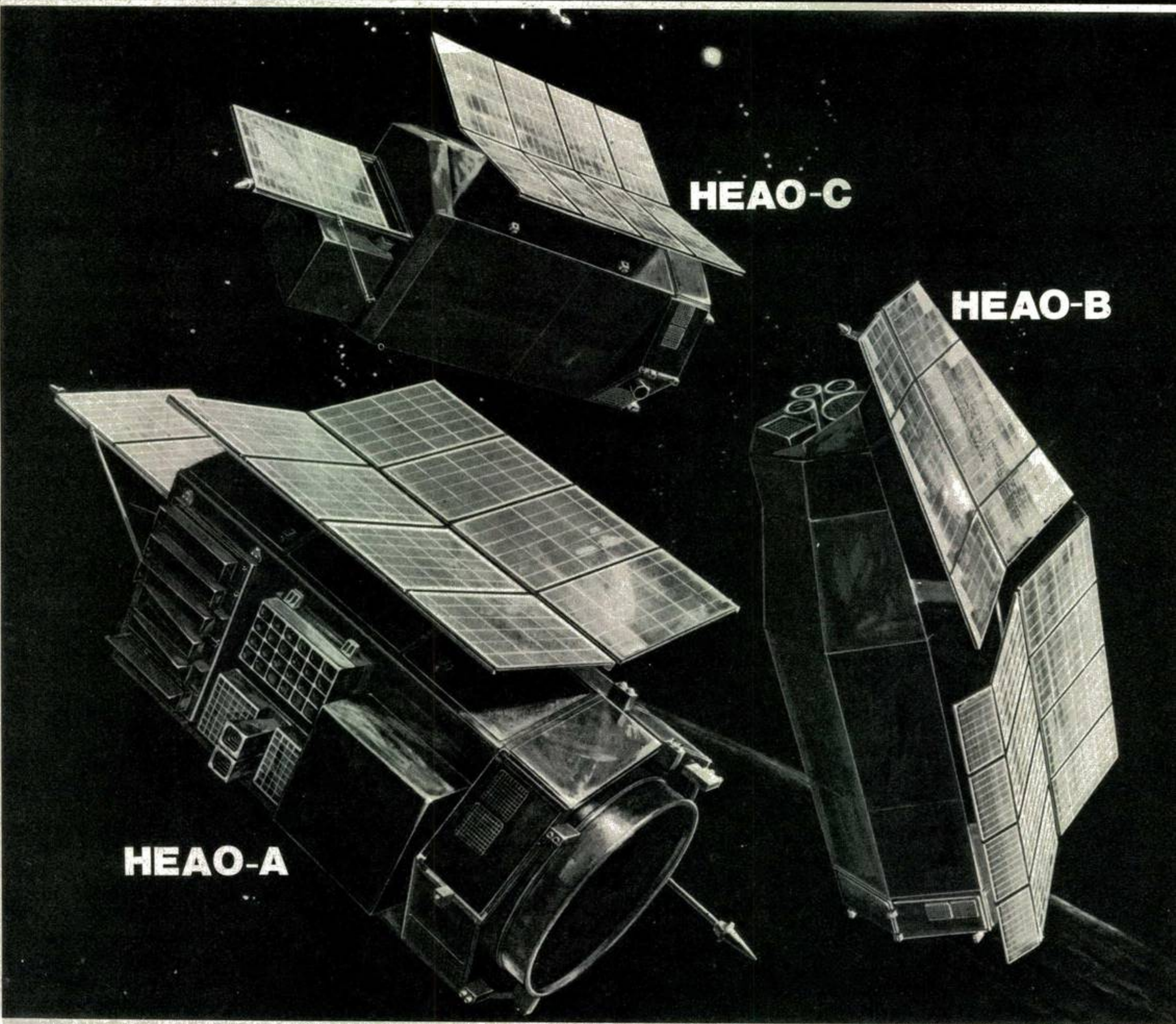
Top left: Some globular clusters, giant balls of 100,000 or more stars that envelop our galaxy, contain x-ray sources. In their centers, stars are a million times denser than they are near the sun; the enormously increased chance of stellar collisions may help explain their x-ray sources. Lick Observatory photograph. Top right: Seyfert galaxies differ from normal galaxies in having an extra-bright galactic nucleus and signs of unusual activity in the core. NGC-4151 is shown here. Hale Observatories photograph. Bottom left: The center of the Coma cluster of galaxies emits x-rays in a source spread through a large area between galaxies. Hale Observatories photograph. Bottom right: The radio galaxy Cygnus A also emits x-rays. How this enigmatic object produces x-rays is not yet known. Lick Observatory photograph.

While there are nine known x-ray pulsars, and probably more not yet discovered, a large number of x-ray sources do not pulsate and hence cannot be confidently classified as neutron stars. Few of these are believed to be neutron stars, and in at least one case (Cygnus X-1), there is strong evidence that an x-ray source is a black hole (see box for details).

Black holes are the final stages of evolution for stars so massive that even nuclear repulsion cannot support them. When a star of mass greater than about three times that of our sun exhausts its nuclear fuel, it begins to collapse. As its radius decreases, its surface gravity becomes stronger until finally the gravity is so great that the escape velocity exceeds that of light. At that point the star turns black because no radiation — and indeed nothing at all — can escape from its gravitational pull.

It seems a contradiction to state that a black hole emits no radiation and yet suspect it of being an x-ray source. In fact, x-rays are emitted from the *vicinity* of the black hole — not from the object itself. In theory, gas coming from the normal star companion of a black hole approaches and begins to rotate around the collapsed star, rather than falling directly into it. It probably forms a rotating disk about the hole. As the matter rotates, the disk becomes denser as friction causes particles to lose

X-Ray *continued on page 18*



Artwork Courtesy TRW, Inc.

What Is A HEAO?

HEAO (another of NASA's many acronyms) is an abbreviation for High Energy Astronomy Observatory. HEAO consists of three unmanned satellites programmed to conduct above-atmosphere studies of some of the mysteries of astrophysics: pulsars and neutron stars, black holes, quasars, radio galaxies and supernovae.

These mysteries of the universe will be explored through the use of x-ray, gamma ray and cosmic ray experiments. This universe has been characterized by what the National Academy of Sciences describes as "a general cosmic violence, exploding galaxies and quasars, an almost universal presence of high energy particles and magnetic fields, and events suggesting relativistic collapse".

Prior to launch, the three satellites are assigned the alphabetical designations A, B and C; these will be changed after launch to numbers 1, 2 and 3. The satellites are scheduled for launch one at a time during each of three consecutive years, beginning in 1977.

The observatories — the heaviest Earth orbiting satellites ever launched (the instruments alone weigh 1-1/2 tons) — will carry scientific instruments capable of detecting, with high sensitivity and resolution, x-ray emissions from sources throughout the universe. Celestial gamma ray and cosmic ray data will also be collected.

These high energy rays cannot be studied with Earth based instruments because the atmosphere usually absorbs them. In earlier days, the rays were observed by instruments on sounding rockets and balloons. Some observations that were carried out by small satellites did not have the instrumentation capabilities necessary for high data resolution and sensitivity. These capabilities are now available in the HEAO satellite. HEAO is inexpensive, too; its spacecraft subsystems take advantage of existing hardware designs developed in other spacecraft programs. About 80 percent of the HEAO hardware is "off the shelf".

Information returned by HEAO may provide clues to the nature of some of the newest discoveries and most mysterious celestial objects in the universe. This knowledge, in turn, could lead to a better understanding of the high energy universe and to new theories about energy production and high density matter.

HEAO-A, the first mission, will survey and map x-ray sources throughout the celestial sphere, and will also measure low energy gamma ray flux. The spacecraft will survey the entire sky in six months. The HEAO-B mission will maneuver and point for long periods at selected x-ray sources mapped by HEAO-A and smaller x-ray spacecraft, while HEAO-C will conduct a survey of gamma ray emissions and study cosmic ray particles from our galaxy.

HEAOs A and C, designed to perform sky surveys, are classified as scanning missions. They will rotate slowly end-over-end, completing one revolution about every 30 minutes. Each will use a gas thrust reaction control system to maintain proper sky scanning orientation, so that the solar arrays face the sun at all times to provide electrical power for the satellite. For HEAO-B, which must point its x-ray telescope at specific stars or points in the sky, reaction wheels are added to provide a precise and highly accurate pointing capability of one minute of arc or better. HEAO-B is termed a celestial pointing mission.

The HEAO-A and C observatories will have a mission lifetime of six months each — the time required to fully map the celestial sphere. HEAO-B will have a mission lifetime of one year for pointing at selected, highly interesting x-ray sources.

The observatories, 19 feet (5.8m) long and weighing between 6,000 and 7,000 pounds (2,700 and 3,100kg) will be placed in low circular orbits, about 225 to 245 miles (420 to 460km) above Earth.

X-rays and gamma rays are composed of photons — particles having energy but no mass, as in visible light rays. Cosmic rays are composed of particles such as electrons and protons, having both mass and energy. X-rays have thousands of times, and gamma rays millions of times, the energy of visible light. It is this "high energy" to which the name High Energy Astronomical Observatory refers.

In high energy astronomy, interest is in the extreme short length waves which are known as x-rays and gamma rays. These rays are produced on Earth in both natural radioactive materials and manmade processes. The x-rays and gamma rays on Earth are produced from well-understood physical processes, and are used routinely in medicine, chemistry, engineering, physics and other scientific and practical fields. This type of radiation is produced by mechanisms involving the atomic and nuclear structure of the elements. Little is known, however, about the way in which x-rays and gamma rays are produced and accelerated from deep space toward Earth with such great energy.

The radiation data collected by the HEAO observatories, after analysis, will probably lead to a better understanding of how the extremely high energies are generated in space, how the basic elements we are made of are formed in the cores of stars, the age of the universe and how it has evolved, and the extreme physical processes evident in pulsars, neutron stars, black holes, and the nuclei of galaxies.

Will HEAO produce practical results? Stars exhibit much more efficient ways of producing energy than the primitive burning which prevails on Earth today. Our sun is a small star, yet one second of its output is equivalent to all the energy ever consumed by humans.

Results from HEAO may ultimately lead to new theories about energy production and high density nuclear matter. "In looking to our local energy resources," says physicist Freeman Dyson, "it is well to consider how we fit into the larger scheme of things. Ultimately what we can do here on Earth will be limited by the same laws that govern the economy of astronomical energy resources."

Prime contractor for the HEAO spacecraft is TRW Systems of Redondo Beach, Calif. TRW's role is to design and develop the HEAO spacecraft, integrate the existing and new experiments into the observatories, and to integrate the missions and support launch operations at Kennedy Space Center. TRW will also perform actual flight operations at the mission control center (Goddard Space Flight Center), under the direction of the flight director of Marshall Space Flight Center. General Dynamics Convair Aerospace Division is the contractor for the Atlas booster stage and the Centaur upper stage.

Information gathered by the HEAO program will be reduced and analyzed by investigators and other scientists from the United States government, representing various industries, universities and other government agencies, as well as other nations.

X-Ray *continued from page 15*

orbital energy. As these particles fall inward through the dense disk, frictional heating raises their temperature so high that they emit x-rays.

Galactic X-Ray Sources

Many other objects in our galaxy can emit x-rays. Supernova remnants and globular clusters, although not as common as the binary compact star emitters, are nonetheless significant in the x-ray universe.

Supernova remnants have been examined closely as sources of stellar x-rays. As debris from the supernova explosion moves outward, it begins to encounter the interstellar medium. An intense shock wave is established as material from behind smashes into the gas of the interstellar medium; the wave heats up to the point where x-rays are emitted. About 10 such supernova remnant x-ray sources are known.

Another collection of x-ray objects that have been extensively studied are the x-ray sources in globular clusters — the symmetric groups of 100,000 or more stars in spheres 50 light-years in diameter. In the centers of these clusters, star density may be as high as a million times more than it is in the vicinity of the sun. Some 150 globular clusters are known; they are arranged in a great halo surrounding the galactic center. Three x-ray sources were found in globular clusters by Uhuru; since then, four more have been discovered. These numbers reveal an important fact concerning globular clusters: Many of the x-ray sources are associated with them. Statistically, the odds of a star in a globular cluster being an x-ray source are seven per million. However, the odds of any other star — such as one in the galaxy — being an x-ray source are about one in a billion. Thus, globular cluster stars are thousands of times more likely to be the sites of x-ray sources than ordinary stars.

Most stars in globular clusters are very old, and have exhausted their nuclear fuel. Those that remain burning are all very "light" (low mass). But low mass stars are unlikely to inhabit a binary system with a neutron star or black hole. This is because neutron stars and black holes are only formed as the result of supernova explosions! Only binary systems in which the normal star is massive can survive disruption during the violence of a supernova. Thus, an ordinary binary x-ray source (consisting of a normal star and a black hole or neutron star) is quite unlikely to exist in a globular cluster. The binary/collapsed star model cannot account for x-ray generation in globular clusters if the binaries simply aren't there!

What, then, are the globular cluster sources? Two models have been proposed which make use of the most outstanding feature of these clusters — their extreme stellar densities. In the first model, x-rays are emitted as they are in the standard binary/neutron star picture: by infall of matter from the companion. But in this view, the binary is formed after the supernova explosion which creates the collapsed star. Several scenarios describe how the collapsed star can gravitationally "capture" its ordinary companion (such an event is vanishingly rare under normal star densities encountered in space). In one, the compact object actually collides with the ordinary star, losing energy by friction as it moves through the atmosphere. With part of the kinetic energy removed, the two stars can eventually settle into a stable orbit around one another, and the evolving star will eventually begin losing mass to its "compact" companion. Clearly, the enormously high density of stars within a globular cluster greatly enhances the probability of chance collisions.

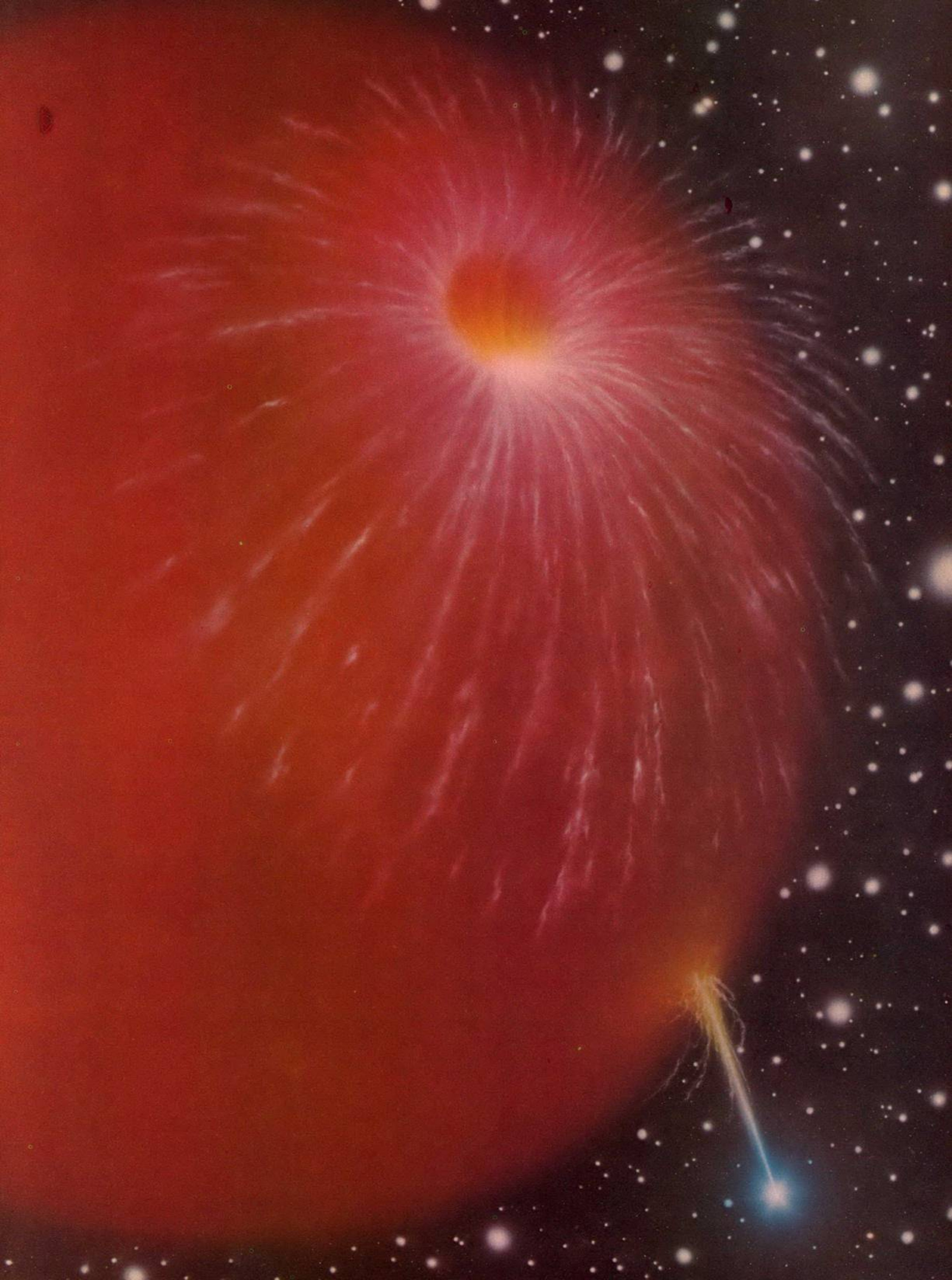
In a second model, we ask, "What happens to remnants of massive stars (presumably black holes) that ceased burning long ago?" Because of the gravitational field of the entire cluster, the collapsed stars gradually sink toward the center — where they eventually coalesce into a giant black hole. Although such a massive object (100 to 1,000 solar masses) collects enough matter from the interstellar medium to serve as an x-ray fuel, an ordinary black hole could attract interstellar gas at a rate high enough to power an x-ray source.

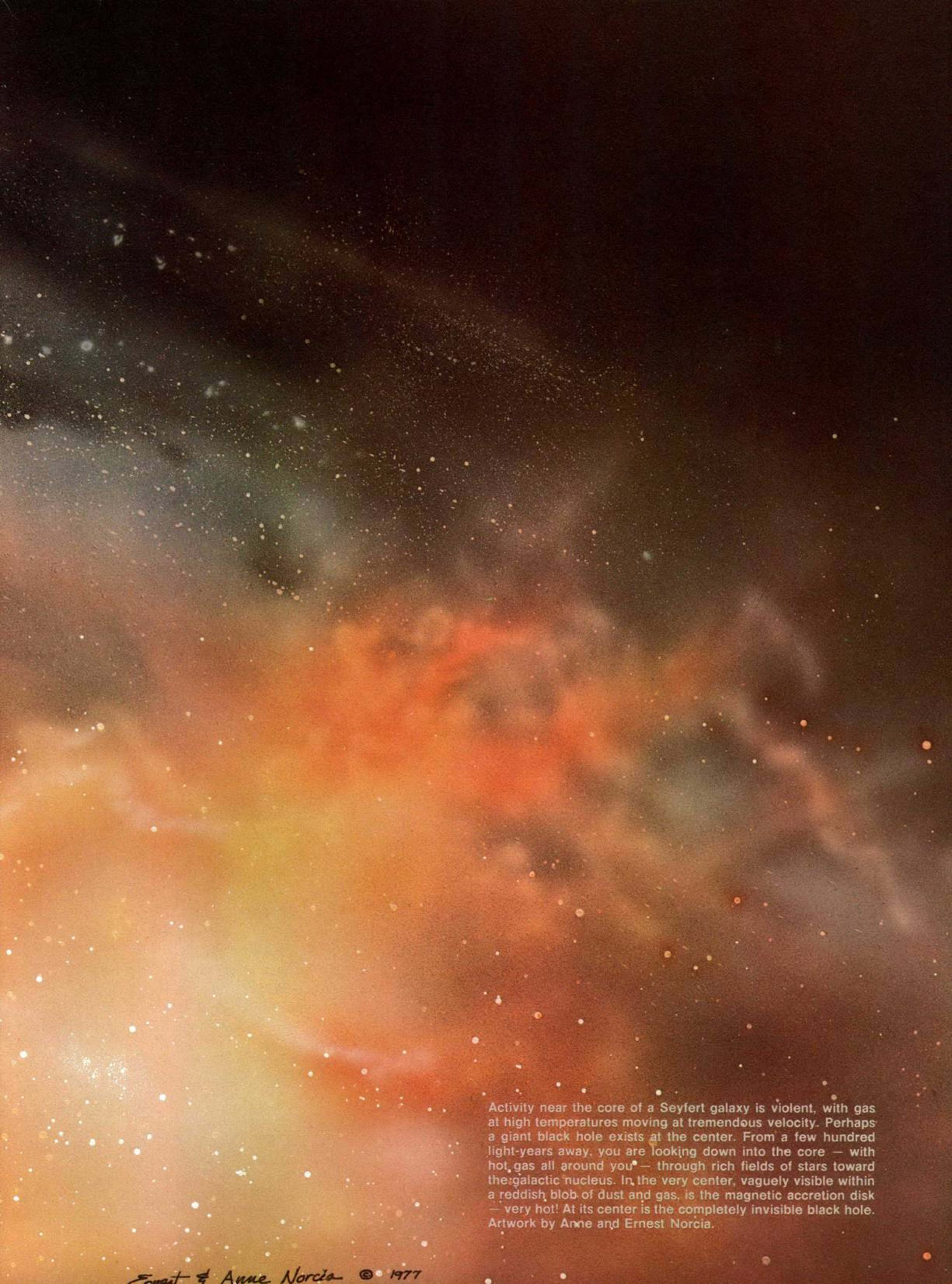
Presently, neither model is generally accepted. Both schools of thought continue to observe globular clusters, hoping to find further evidence in support of their viewpoints. One such observation which has proved immensely exciting — although not particularly helpful in resolving the debate — is the discovery of *giant x-ray bursts.*

X-ray bursts are sudden, large increases in the amount of x-rays from an object. In about one second they rise from a quiescent level to peak intensity, often 10 times as great as is normally seen from galactic sources. In about 10 seconds, they die out. They were first reported by a Soviet group in 1975, but great interest was not aroused until late 1975 when two American groups found that such bursts were associated with a globular cluster x-ray source. Immediately a search began for other burst sources. About 25 have so far been discovered in our galaxy.

One of the most intriguing properties of the burst sources is the occurrence of trains or series of bursts. The interval between burst events, usually a few hours, is almost constant. Although such periodicity is suggestive of a binary or pulsar system, such an interpretation unfortunately had to

In the heart of a globular cluster of stars, a given volume of space has a million times more stars than the space around our sun. Collisions between stars — too rare to consider near the sun — are much more frequent and may account for the large number of globular clusters containing x-ray sources. Here, much slowed by friction, a white dwarf star exits from a red giant star it has encountered. The white dwarf may now go into orbit about the giant, settling into a close orbit where mass lost from the giant will accrete onto the white dwarf and emit x-rays. Artwork by Adolf Schaller.





Activity near the core of a Seyfert galaxy is violent, with gas at high temperatures moving at tremendous velocity. Perhaps a giant black hole exists at the center. From a few hundred light-years away, you are looking down into the core — with hot gas all around you — through rich fields of stars toward the galactic nucleus. In the very center, vaguely visible within a reddish blob of dust and gas, is the magnetic accretion disk — very hot! At its center is the completely invisible black hole. Artwork by Anne and Ernest Norcia.

be discarded almost at once: The bursts do not occur truly periodically. The interval between bursts jitters around an average value, varying a few percent. Furthermore, for most burst sources, the phenomena come and go; several months may pass during which no bursts at all are observed. When the bursts return, the bursting interval may have changed! Such changes are inconsistent with the nearly perfect timing of binary or pulsar motion.

Despite careful satellite studies of bursts in globular clusters, little light was shed on the nature of the x-ray emission mechanism. Both models that explain ordinary x-ray emission from globulars could be modified to explain bursts! The interpretation using massive black holes at the cluster center suggested that bursts are caused by an ordinary star "crashing" through the disk of accreting matter as it orbits the central black hole. Such collisions, disturbing the smooth flow of matter, would generate instabilities in the accretion disk. The disturbances would recur periodically, and would manifest themselves as bursts.

Astronomers who favor the captured binary school of thought view the bursts as instabilities in the mass accretion process onto a magnetized neutron star. In this scheme, the plasma builds up and is held outside the star by the pressure of the magnetic field. At some point, this unstable situation is relieved by a sudden surge of matter onto the poles of the star — and a burst of x-rays. This model has the advantage of not being peculiar to a globular cluster source; thus, it can be used to explain burst sources that are found at many locations throughout the galaxy.

Extragalactic X-Ray Sources

As we look outside the galaxy, we must consider x-ray emission on a much larger scale — both in terms of the physical sizes and the times involved. Unfortunately we are also faced with much greater distances, so that the number of x-ray photons that reaches us from extragalactic objects is much smaller than from galactic sources (though the number of photons *emitted* by extragalactic objects is several orders of magnitude greater). Consequently, less is known about the sources outside the galaxy.

X-rays have been observed from the following types of objects: ordinary galaxies, radio galaxies, Seyfert galaxies, quasistellar objects (QSOs) and clusters of galaxies. X-ray emission from ordinary galaxies (such as our own) and M-31 is well understood: It is simply the total of all the radiation from individual sources within the galaxy. Radio galaxies, Seyfert galaxies, and QSOs are not as simple; it is apparent that some unusual events and physical processes must be taking place. For some quasars (which are the most distant entities in the universe), the x-ray luminosity is a million times greater than our own galaxy's.

No theory is widely accepted by astrophysicists to explain this incredible x-ray intensity. But a class of theories being developed pictures supermassive objects (probably black holes) at the centers of these exotic objects such an object would be so massive (greater than one million solar masses) that it could power itself by accreting interstellar matter as globular cluster burst sources might, or even by swallowing entire stars. Details of the radio, optical and x-ray emission from such an object are still being worked out. In fact, the main virtues of these theories are that they fit the rather meager observations and supply an easily understood energy source — matter falling onto a supermassive object — that can produce the equivalent of a million suns' energy output.

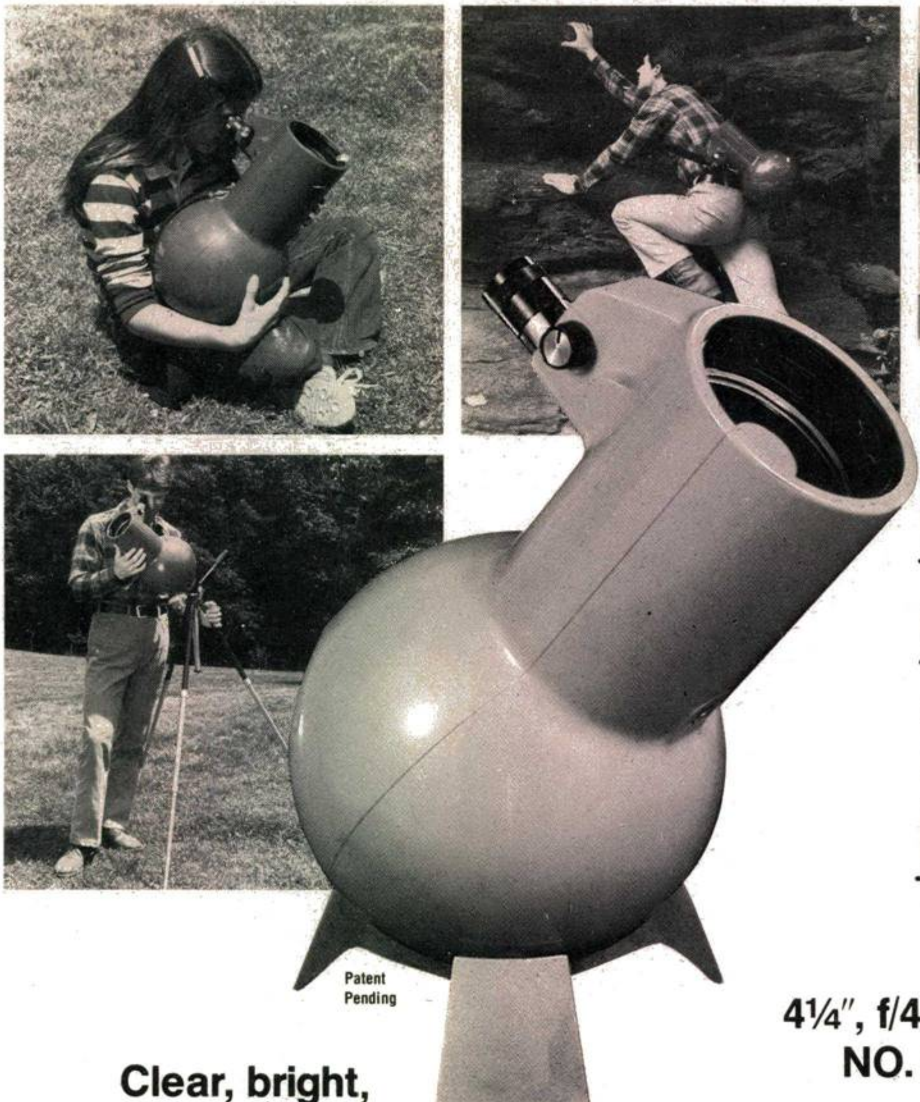
The largest objects in the universe are also x-ray sources: clusters of galaxies — groups of hundreds to thousands of galaxies orbiting a common center in associations, some tens of millions of light-years in diameter. From these clusters, the x-ray emission is 10 to 100 times as great as the expected total produced by the individual galaxies that make up the clusters. The observational evidence indicates that, for most galaxy clusters, x-ray emission is distributed throughout the cluster and does not come from a single individual active object. Although most astronomers and astrophysicists feel the x-rays must be emitted by hot intergalactic gas, the process that heats the gas is simply not understood.

The Next Decade

From as close as the sun to the edges of the universe, we have seen x-ray emission. Through x-rays, astronomers have resurveyed the entire sky in a new wavelength region, making fascinating new discoveries which might never have been made without x-rays.

In the near future we can expect more and more fascinating results — building on the first 15 years of x-ray astronomy. We can look forward to entirely new and unexpected discoveries, and expect to find out much more about the stranger animals in the astrophysical "zoo". While we cannot predict what these findings will be, we can be assured (on the basis of past experience) that they will be made. As Bruno Rossi, one of the fathers of the field, said in describing the motivation for the 1962 rocket flight that began extrasolar x-ray astronomy, it was in part "a subconscious faith in the unending wealth of nature" that inspired the first x-ray experiments, for which there was then little rational expectation of success.

Thomas Markert received his Ph.D in astrophysics from M.I.T. in 1975, and now works at the Center for Space Research at M.I.T. He has worked on three satellites: the OSO-7 x-ray experiments, the SAS-3 (a satellite devoted entirely to x-ray astronomy), and on planning for HEAO-B to be launched next year. Thomas Pencek is a communications consultant and a writer for a major pharmaceutical firm. He is now enrolled in Boston University's School of Public Communication.



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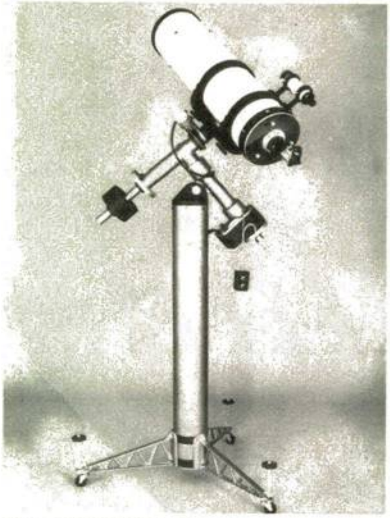

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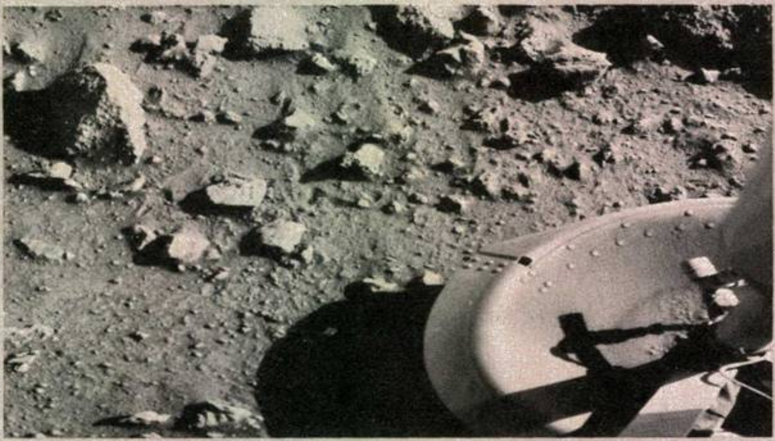

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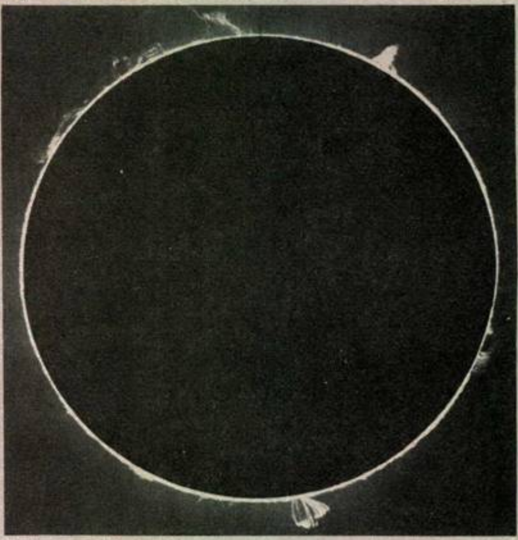

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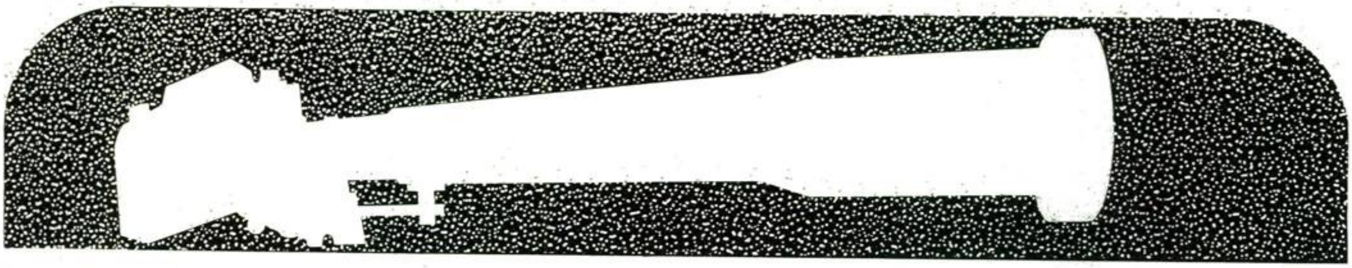

Astrophotography With Telephoto Lenses

by
David Healy

That telephoto lens lying around in your camera bag may be a powerful instrument for astrophotography. Look at it this way: If your lens happens to be a 200mm f/3.5 telephoto, it is also a 2-1/4 inch (57mm) richest field photographic refractor, capable of recording faint nebulae, galaxies and stars only 1/1,500 as bright as the dimmest visible to the naked eye! Why not try it out?

In principle, astrophotography with telephoto lenses is simply an extension of the "piggybacking" idea. You use a clock driven, equatorially mounted telescope as a guidescope and platform for a camera and lens combination mounted on it. Although astronomical photographs can be taken without an equatorial mount from a fixed tripod, the exposure times are severely *limited* by Earth's rotation, which causes astronomical images to trail on the film. A five second exposure with a 200mm focal length

Orion's belt and sword, one of the most colorful regions in the sky, shine brilliantly in this magnificent telephoto lens astrophotograph. A 135mm at f/2.5 was used with Fuji R-100 color film for a 50 minute exposure. The camera was mounted piggyback on the tracking telescope; with a focal length of 135mm, tracking was easy. Photograph by David Healy.

lens, for example, is about the maximum that can be taken without objectionable trailing. Five seconds is long enough to overexpose the moon and record naked eye stars, but far short of the time needed to photograph most deep sky objects which usually require exposures in the 500+ seconds range. The beauty of long exposure deep sky photographs is, of course, that faint images have a chance to build up on the film. Most "garden variety" telephoto lenses, if handled properly, can record celestial colors and detail that the world's largest telescopes, used visually, would not reveal.

Field of View

How much will your lens show? How much do you want to record? Telephoto lenses are best when the object or area to be photographed is too large (in angular diameter) to fit into the field of view of a telescope (often one degree or less), but too small to show well with "normal" camera lenses. Normal lenses have an enormous field of view — about 28 by 40 degrees. For reference, a few well-known celestial angular diameters are:

Diameter of full moon	1/2°
Width of Orion's belt	2-3/4°
Distance between "pointer" stars, Big Dipper	5-1/2°
Across Orion from Betelgeuse to Rigel	18-3/4°
Nearest "pointer" star (αUMa) to pole star	29°

You should know — at least roughly — the field of view of your telephoto lens and the size in degrees of the area or object to be photographed. If you know its focal length, you can find a lens' field of view by the approximate formula:

$$\text{field coverage in degrees} = \frac{57.3}{\text{lens EFL (mm)}} \times \text{film format dimensions (mm)}$$

So, for example, if your telephoto lens has a 200mm effective focal length, and your film format dimensions are those of a 35mm camera (24mm x 36mm), the field coverage is:

$$\frac{57.3}{200\text{mm}} \times \begin{matrix} 24\text{mm} = 6.9^\circ \text{ (vertically)} \\ 36\text{mm} = 10.3^\circ \text{ (horizontally)} \end{matrix}$$

For the usual focal lengths available in telephoto lenses, the fields are already worked out for you in table 1.

What to Photograph

A table of suitable celestial scenery for telephoto lenses is on page 30. Some of the objects (like Orion's belt) you've probably seen again and again and again — and they're still beautiful. But

Angular Fields of Telephoto Lenses

Focal Length	24mm dimension	36mm dimension
50	28°	40°
85	16°	24°
105	13°	19°
135	10°	15°
150	9.2°	13.8°
200	6.9°	10.3°
250	5.6°	8.2°
300	4.6°	6.9°
400	3.4°	5.2°
500	2.8°	4.1°

there is more to try in the rest of the sky, and the list has some of those objects too. The Virgo cluster of galaxies is a telephoto lens subject, and there are hundreds of galaxies in it. Of course don't expect wonders; they'll show up as little fuzzy spots, each a distant galaxy. The comments are intended to help you choose the best ones for your location, sky and film choice.

There are many other possibilities as well. Although the moon's diameter is still quite small in a photograph taken with a 200mm telephoto, eclipse or lunar occultation photos including some foreground detail can be quite rewarding. Exposures are short, ranging from a fraction of a second to five seconds or so, and no clock driven mounting is required. When prints are made from any of these photographs, of course, tiny portions of the negatives or color slides can be enlarged, and the uninteresting areas cropped out. Long exposure photography of comets is another task for which the 135mm telephoto lens is well suited, because of its relatively wide field (see "Photograph a Comet", ASTRONOMY, February 1976). Exposure times should be rather long; faint details of a comet's tail show best when the exposure is just short of the time that would overexpose the sky fog background — for example, 25 minutes at f/2.5 with GAF 500 film in a dark sky area.

Films

An enormous amount of footage of perfectly good Kodak color film is wasted by astronomy enthusiasts trying to take long exposure deep sky photographs with it. It can be done, but results are almost always disappointing because of a phenomenon known as *reciprocity* failure. Kodak color films lose their effective ASA speed (or sensitivity) to an unacceptable degree during prolonged exposures of dim objects, unless the film is chilled to dry ice temperatures *during* exposure (see "Cold Cameras, Parts 1 and 2", ASTRONOMY, February and March 1977). The new E-6 process Ektachrome films (Ektachrome 200 Professional Film) may be better for deep sky work, but for the results obtained, exposures seem unnecessarily long and the slides have a greenish cast.

Perhaps the finest color film for your deep sky work is Fujichrome R-100; its advantages are its fine grain and good red sensitivity, but it is a rather slow film. Fuji R-100 slides usually appear reddish. The grainy and blue sensitive GAF 500 film can usually record the same object as R-100 in 1/2 to 1/3 the exposure time. GAF 500 slides often appear bluish. Users differ on the value of GAF 200 as a deep sky film: Some say it is somewhat better than GAF 500; others say almost as good (see "Is Faster Better?", ASTRONOMY, December 1976). Specifications for the new Fuji ASA 400 color print film suggest it has severe reciprocity failure (that is, +3 stops compensation needed at 100 seconds exposure). Fuji II-400 film may not be of much use astronomically.

If you can develop your own film (or convince your photo lab to follow some special instructions), the Kodak 103a- series films are by far the best choices for black and white telephoto shots. Better known emulsions in this series include 103aO (blue sensitive), 103aE (red sensitive), and 103aF (panchromatic). Designed for astronomical use, they have little or no reciprocity failure in long exposures. 103aE seems considerably faster than 103aF (perhaps about ASA 600), and is ideal for red filtered photography which permits deep sky photography from smoggy and light polluted areas (see "Red Light Sky Photography", ASTRONOMY, August 1976). Not found in camera stores, 103a- films can be obtained in 100 foot rolls or in 36 exposure, 35mm size rolls from: Optica b/c Company, 4100 MacArthur Blvd., Dept. A, Oakland, Calif. 94619; Astro Cards, 156 Beale Rd., Dept. A, Sarver, Pa. 16055, or Astrofilm, P.O. Box 2731, Dept. A, Akron, OH 44301. These extremely sensitive emulsions last indefinitely if given freezer storage. They should be developed in D-19 rather than in a conventional developer, should have a water (rather than an acid) stop bath, and usually need swabbing with developer during the fixing process to remove traces of the antihalation backing with which it is generally supplied. This much special handling may sound troublesome, but the 103a- films give results that are worth it: You can profoundly extend your deep sky reach.

Setting Up

Necessary for telephoto lens astrophotography

Top: Telephoto lenses get you closer to fascinating sky events. When the moon occulted Venus in July 1974, a five second exposure on Kodachrome 64 using a 200mm f/3.5 telephoto with the camera mounted on a stationary tripod yielded this beautiful scene. Photograph by David Healy. Middle: Long telephotos get you still closer. The Orion nebula is recorded here with a 500mm f/6.3 telephoto lens on Eastman 5247 film (an ASA 400 film by Kodak) in a 40 minute exposure. Photograph by Phil Poirier. Bottom: Deneb and the North America nebula posed 40 minutes for their telephoto lens portrait; GAF 500 film was used with a piggybacked 200mm f/3.5 lens. Photograph by David Healy.

is a reliable method of mounting the camera-plus-lens combination on the clock driven telescope. Some telescope makers offer camera mounts as accessories, and some suppliers of astronomical hardware (such as Roger Tuthill and Optica b/c) offer camera mounts that will fit different sized telescopes. These consist of a standard camera tripod head attached to a metal band or clamp that encircles the telescope tube. Obviously, a firm mounting is essential to avoid photographs produced by a carefully guided telescope topped by a telephoto lens that is slowly sliding out of position. A variant on this would be pointing the guidescope at the desired object, and the telephoto lens at something else — say, 10 degrees to the east or west. A good check for this sort of alignment is to line up a bright star in the guiding telescope's eyepiece and make sure that the star can also be seen in the center of the camera's viewfinder.

This check also eliminates the possibility of gross focusing errors and, of course, the possibility of leaving the lens cap on. Focusing through a telephoto lens at night, however, can be difficult and/or unreliable for various reasons; it's best to simply set the lens on "infinity". While you're hovering about your camera/telescope combination, recheck to make sure that the lens' f/stop is set correctly, and that the shutter speed is set at "time" or "bulb". The latter setting, with a locking cable release to hold the shutter open during exposure, would probably be better. (This checklist may seem grossly simple and unnecessary — but on the contrary, it *is* necessary.)

Common Astronomical Subjects for Telephoto Lenses

Pleiades (B)
M-31 (B)
Starcloud in Sagittarius
Lagoon and Trifid (R)
Orion's belt and Horsehead (R)
Orion's sword and M-42
Double cluster
California nebula (R)
Hyades
Beehive
Southern Auriga star clusters
North America nebula (R)
Gamma Cygni nebula (R)
Cygnus Loop nebula (R)
Cygnus starcloud (B)
Scutum starcloud
Rosette nebula (R)
Triangulum nebula (B)
Virgo cluster of galaxies (B)
Hercules globular cluster
Eagle and M-17 (R)
Antares region

R = best photographed in red light
B = best photographed in blue light

Polar Alignment

The right ascension axis of the driving telescope must be reasonably well-aligned on the celestial pole — otherwise the stars in your photograph will make concentric arcs around your guide star (a phenomenon known as *field rotation*). There seem to be as many alignment methods as there are telescope makers and authors of "how to" articles. A method, using the telescope's finder only, that is quick and works well is described in more detail in "Astrophotography . . . In Spite of Myself" (ASTRONOMY, April 1976). Essentially, with the telescope's declination set at 90 degrees, you turn the scope in right ascension until its declination axis is perpendicular to the imaginary line running from the star at the end of the Big Dipper's handle (by the pole star) to the easternmost star in the "W" of Cassiopeia. If the finderscope is aligned with the main scope's optics, then the scope will be in polar alignment when the pole star appears .8 degrees from the center of the finder field, along the crosshair that parallels the Dipper-Polaris-Cassiopeia line in the sky. Polaris should appear on the crosshair in the same side of the field as the Big Dipper is in the sky, or on the opposite side from Cassiopeia. This is true because while the north celestial pole is about .8 degrees from the pole star in the direction of the Big Dipper's handle, this orientation is optically reversed in the typical finderscope.

Dewing

The collapsible rubber lens hoods, often sold as accessories for telephoto lenses, are inadequate to prevent moisture from condensing on the lens and ruining a photograph. A long dew cap works much better, and is desirable even in dry areas to shield the film from the parade of cars (with high beams on) that are always attracted by opening of the shutter. You can build "low technology" dewcaps for any of your lenses — perhaps consisting of a tomato soup can and a radiator hose clamp, all painted flat black. On some damp nights a dewcap is inadequate to keep the lens clear during a longer exposure, but you can periodically "blow dry" the lens from one side — *during* the exposure — with a hair dryer, without degrading the photograph.

Guiding

Good telephoto lens astrophotography requires that the guiding telescope be equipped with a drive corrector in right ascension, a fine slow motion control in declination, and a guiding eyepiece with illuminated crosshairs. The intent is to keep a guide star centered in the telescope's eyepiece while the exposure is being made. Telephoto lens guiding tolerances are more critical than in piggyback photography with normal lenses, where drive correctors and slow motion controls may not be necessary.

On the other hand, guiding errors that might ruin a through-the-telescope photo may not show up in a telephoto shot. The fact that the image of a bright star can be pretty big on a telephoto photograph suggests that guiding errors — if promptly corrected — aren't always fatal!

Lens Quality

Some telephoto lenses were obviously not designed with astronomy in mind. A common problem is distortion of star images toward the edge of the field when the lens is opened up to its full aperture. Knowing ahead of time whether a particular lens has this failing is difficult. Usually, the higher priced the lens, the greater its virtues at full aperture — though this is not always the case. For example, Takumar (Pentax) 200mm and 135mm lenses behave well wide open, but this is more good luck than good management if you acquire the lenses long before becoming interested in astronomy.

Popular Photography publishes tests on many brands of lenses, including a "star" test. Reprints are available at $1 each (minimum order $3, plus applicable sales tax) from Popular Photography Information Center, Consumer Service Division, 595 Broadway, New York, NY 10012. Test reports cover Takumar, Leitz, Canon FD, Nikkor, Leicaflex, Fujinon, Olympus, Kowa, and Pentax 6x7 lenses. Most lenses do give satisfactory results.

Stopping down the lens to a smaller aperture usually does wonders to cure some lens fuzziness. A Soligor telephoto lens can be virtually worthless at its full f/1.8 aperture, but yields a quite presentable astrophoto when closed down one stop to f/2.5. An inexpensive Spiratone lens of the same aperture is great "wide open" at f/1.8, so you may have to shop around a bit. Of course, your exposure time must increase to compensate for stopping down the lens — for each full f/stop the exposure time must be doubled, neglecting the effects of any film reciprocity failure. If you buy a telephoto lens for astrophotography, most camera stores of good reputation will let you "check it out" with return privileges if it isn't good enough.

Murphy's Third Law

Don't forget that Murphy's Third Law, "Nature Always Sides With the Hidden Flaw", is a basic principle of astrophotography, either with or without telephoto lenses. In starting out to take guided deep sky pictures, you can reasonably expect to make most of the mistakes we've mentioned here as well as inventing some new ones. In the process you will chew up a great deal of film footage before getting a rewarding photograph. But with good conditions and some patience, you can produce professional looking color celestial photographs with a telephoto lens.

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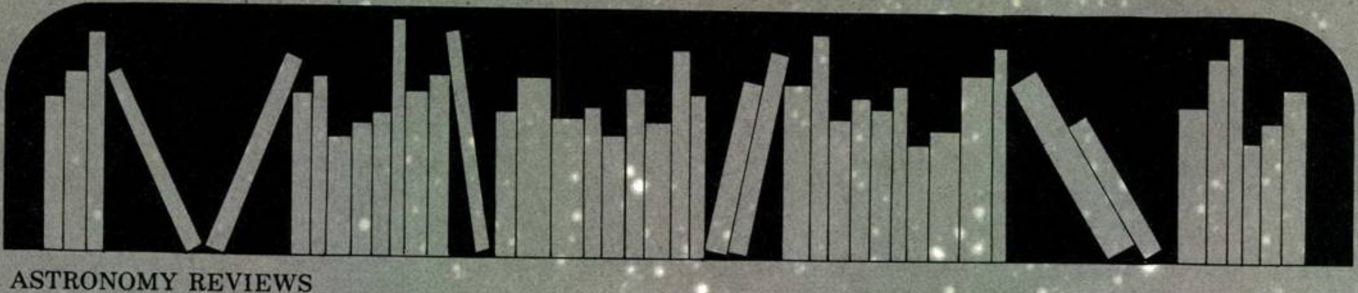

ASTRONOMY REVIEWS

A Primer in Lunar Geology
edited by RONALD GREELEY

574 pages, paperback, $13.00
National Technical Information Service (1975)

On a grant from NASA, a group of space scientists met in California to develop a course on lunar geology which could be taught in community colleges. This book is the collection of papers, reports and study guides which were assembled for that course — a course which any astronomy buff could take at home, just by reading.

Separate sections discuss the formation of the solar system, Earth and the moon; then meteorites, selenology, impact craters, geologic mapping of Earth and the moon, and finally the lunar basins and volcanos. Scientific results of each Apollo mission are detailed, and a separate section on Martian geology may help explain the Viking results. Lastly, a large chapter covers teaching methods, laboratory experiments, and access to other teaching resources.

Illustrations include paintings of the moon before, during, and just after formation of the maria, and excellent photos of terrestrial lava collapse tubes which are part of the best explanation so far published for lunar sinuous rilles. The whole package is a very valuable learning tool. *James E. Oberg.*

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* * *

Beginner's Guide to Astronomical Telescope Making
by JAMES MUIRDEN

201 pages (illus.), hardcover, $12.50
Pelham Books Ltd. (1975)*

Any newcomer to the fascinating hobby of telescope making quickly learns that, although there are many so-called mirror grinding "kits" available on the market today, none of these includes the kind of step-by-step instructions usually associated with "unassembled" or "unfinished" products. On the contrary, little or no advice accompanies such kits, and a good book on the subject is indispensable if your first telescope making project is to be a success.

Beginner's Guide to Astronomical Telescope Making is a first-rate "how-to-do-it" book written expressly for beginners, and providing a wealth of useful information. Its purpose is simple — "to help the frustrated observer make, in the shortest possible time, a powerful and effective astronomical telescope" — a six inch reflector. This is a goal well within the reach of anyone "even remotely good with his hands" who has the patience to become a good astronomer. According to Muirden, if you have what it takes to be a good observer, then you have what it takes to build yourself an excellent instrument with which to observe!

One of the obvious strengths of this book is that it includes much, much more than the usual plans for building the "standard" six inch reflector. After an introductory chapter about the general history of telescopes and some basic facts about the nature of light itself, Muirden explains how to construct a small, easily built refractor. His design utilizes simple (non-achromatic) lenses — perhaps the close-up lenses from your camera bag! — and results in a very inexpensive, yet effective, instrument. This experience quickly gives the beginner the satisfaction of creating his own first telescope, introduces him to some basic information about optics, and whets his appetite for bigger and better things to come.

At the other end of the spectrum, this guide also contains information about advanced telescope making, including chapters describing larger reflectors, achromatic refractors, and several kinds of Cassegrains. Muirden's treatment of these subjects is much less superficial than that found in other similar books. Appropriate equations (difficult to find elsewhere) are listed, and an entire chapter is devoted to objective lens grinding. While anyone undertaking such advanced projects would probably want to consult additional sources, this book is an excellent place to start.

Although **Beginner's Guide** has very few weaknesses, two, in particular, should be noted. First, the section dealing with pitch laps and mirror polishing seems somewhat outdated. Muirden's method of making the lap consists of cutting individual facets after the pitch has been poured on the tool. This is very time consuming and frustrating; with new rubber molds currently available from many suppliers, better results can be obtained more quickly, easily, and at little additional cost.

Second, because this book was first published in Great Britain, references are only made to suppliers of materials from that country. U.S. readers will have to look elsewhere for information about ordering parts or aluminizing their mirrors.

Despite its drawbacks, this book is highly recommended. The language throughout is clear, concise and easy to follow; formulas are used only when necessary. A nice balance is maintained throughout between precision and simplicity. Some telescope making books overemphasize the goal of producing the "perfect" mirror, making the task seem almost hopeless; others take such a casual attitude that you might think that mirrors polish and figure themselves! Muirden's book avoids both unfair exaggerations.

Beginner's Guide is filled with the telescope maker's spirit. It's obvious it is written by a man who has been fascinated by the subject — "the fascinating world of optical work, where molecules are molehills and microns are mountains, and wavelengths of light are no longer infinitesimal abstractions but represent very real amounts of glass." Says Muirden in his introduction: "There is something majestic in the balance between the fundamentals of optical accuracy on the one hand, and the supreme vastness of the universe on the other; and the thought that one has labored with eye and hand to such fine limits to reveal what is . . . so unimaginably vast, gives inspiration to the observer's work that must be lacking in the use of a manufactured instrument . . . ."

Readers who are left uninspired by such a statement should probably look for a book on another subject. For those who are inspired, no further recommendation of this one should be necessary! *Thomas C. Bretl.*

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* * *

Growth Rhythms and the History of the Earth's Rotation

edited by G.D. ROSENBERG and S.K. RUNCORN

559 pages (illus.), hardcover, $57.00
John Wiley & Sons, Inc. (1975)

Superficially, Earth's spin defines one of our main constants of time: the day. Together with the month and year, this period of time (or subintervals of it such as hours, minutes and seconds) has been used as the yardstick interval against which to measure the duration of events.

But the spin of Earth is not constant. There are wobbles and jerks in it, as well as a long-term, consistent slowing down. The advent of modern technology has allowed astronomers and geologists to chart the recent behavior of Earth's rotation by direct measurement. Along the way, they have adopted a more constant "second", measured in terms of atomic vibrations.

This college level book is intended to be an introduction to the techniques of determining the history of Earth's rotation during past ages when direct measurements were not possible. Amazing and incredibly subtle methods are described by astronomers, molluscan physiologists (read the book to find out what that is!), geophysicists, paleontologists, archeologists, archivists and geologists.

The history of Earth's rotation, and its connection with our moon's motion around our planet, is important to cosmology (is gravity weakening?), geophysics (what is the mass distribution of Earth?), biology (what were the terrestrial conditions under which life formed?), planetology (what was the early dynamical history of the Earth-moon system?), and numerous other disciplines.

While not easy, casual reading, the book opens new avenues of communications between astronomers and other scientists who quite unexpectedly possess information vital to many astronomical problems. An appropriate quotation by psychologist Abraham Maslow comprises a forward to the book: "Science needs all kinds of people . . . since each person can ask different questions and see different worlds."

Certain mollusks (hard shelled primitive sea creatures) show traces of both daily and monthly cycles in their growth rings, which survive as fossils or which are collected from modern specimens fresh from the sea. Several papers attempt to calibrate such traces and extend the approach back to fossils more than 100,000,000 years old. Earth's spin was almost twice as fast then, and the month was about 12 modern days long.

The second half of the book deals with geophysical and astronomical aspects of the problem. Astronomy enthusiasts will find these chapters as intriguing as the molluscan papers are baffling. The role of tides, magnetic reversals, continental drift, solar variability, isostatic uplift of continents once weighted down with glaciers, and more, are postulated. A long and fascinating chapter on ancient solar eclipse observations attempts to establish the slowdown rate over the past 3,000 years.

While not written for astronomy enthusiasts, the papers in this book (actually the proceedings of a special conference) offer special insights to astronomers. They are well edited and, with many illustrations, can be read with concentration. The book shows one more exciting view of the progress of science made possible by breaking down the walls of specialization, while still keeping skilled specialists at work in unison. *James E. Oberg.*

◆

ASTRONOMY: The Evolving Universe

by MICHAEL ZEILIK

529 pages, hardcover, $13.95
Harper & Row (1976)

Competing with a galaxy full of introductory college level astronomy texts on today's market, a new offering has to be very special indeed to stand out among them. Zeilik's **Astronomy: The Evolving Universe** is such a book.

From the very beginning, a refreshing openness by the author to his intended readers is evident. He informs us, for example, that his book emphasizes those aspects of astronomy which his own students have expressed greatest curiosity about, and solicits comments from its users to him at the University of New Mexico.

Zeilik's appealing philosophical approach to dispensing astronomical knowledge can be seen in comments like the following: "In this text I have tried to highlight those crucial cosmic connections that make us all children of the stars." This theme is carried throughout the book, aided by a superb collection of appropriate quotations enriching each and every chapter.

Astronomy is divided into four basic and logical parts, each a veritable book in itself. "Part I: Man's Conception of the Cosmos", gives an excellent historical perspective beginning with observational astronomy and ending with contemporary cosmology. "Part II: The Kingdom of the Sun", is a basic survey of the solar system with emphasis on the exciting results gleaned from space exploration. "Part III: The Universe of Stars and Galaxies", contains one of the best accounts of stars and stellar systems to be found in print today. "Part IV: Cosmic Evolution", is a mind expanding look at the latest ideas in cosmology and the prospects for the existence of intelligent life elsewhere in the universe.

While lacking the spectacular color reproductions of sky objects found in many recent books, **Astronomy** is nonetheless quite attractive in appearance and layout. An effective blue print on white or sometimes pale blue background is both restful to the eyes and commanding of attention. The book is profusely illustrated with diagrams, drawings and photographs — both familiar and new — all done in the blue motif. The cover itself has an unusual full color design that makes it impossible to resist opening and exploring its contents.

Specific learning objectives begin each chapter and a summary of fundamental ideas presented concludes each one — a useful feature for both students and teachers. Boxes are used throughout the book to develop important physical or astronomical concepts in greater detail than in the text itself. These sections can be studied separately and at a later time as need or interest warrant, and perhaps even dropped entirely by general interest readers wishing to avoid technical details. Thus, the text is fast paced and uncluttered, and makes for an exciting adventure in learning.

Judging from his writing, Zeilik must be a very effective and inspiring teacher. His deep concern and feeling for both subject and student are moving, as revealed in the following commentary: "This book is about first and last things. Use it to grow in your awareness of the universe. And so grow in yourself. Do not be blinded by the glories of the cosmos. Yes, the universe is big enough to hold all of us. But you are larger. And much more important."

Another example of this empathy is found in the closing words of the book: "I hope that what I have written may help you to find a little of your own peace in this often mysterious, awesome universe." Oh, for more teachers and scientists with such sensitivity!

Astronomy is not only one of the best and most unusual college texts available today, but is a stirring account of the wonders and workings of the science of astronomy for all who ponder the night sky. Three words sum up this dynamic book: fresh — stimulating — and dependable! *James Mullaney.*

◆

Midsummer Mornings' Planets

July will be an interesting month for planetary observing, as the planets dance in and out of conjunction with each other. The glittering tableau of Mars, Venus and Jupiter not far apart in the morning sky provides one of the year's brightest displays, while the moon passes these planets in review on the 11th, 12th and 13th. The warm summer mornings are an added enticement for early rising and enjoyment of the sight of our neighboring worlds.

Mercury

Having passed superior conjunction with the sun on June 29, Mercury will gradually climb into view during the evenings of July, reaching greatest western elongation on Aug. 8. The coming appearance of Mercury will not be a very favorable one, as the ecliptic has a low tilt with respect to the horizon; thus, Mercury's elevation will not be high. Seeking the planet out, however, can be an absorbing occupation. Try scanning the eastern horizon each evening with binoculars to see on what date Mercury first becomes visible.

Some close approaches of the planet to other celestial bodies may help you in your search. On July 14, Mercury will skirt the northern edge of M-44, the Beehive cluster in Cancer. The cluster itself will also be close to the horizon, and if you want to spot Mercury among its stars, optical aid is essential. At magnitude -0.7, Mercury will be much brighter than any of the Beehive stars.

A double challenge presents itself on July 17, when Mercury will be about six degrees north of the crescent moon. Since the moon will be only about 42 hours old, it will be an extremely thin crescent very low in the west at sunset. Unless you have a clear western horizon, you may miss both the moon and Mercury.

Two days later, on July 19, Mercury will be 0.4 degrees north of Saturn. Mercury's magnitude will be about -0.3 — about one full magnitude brighter than Saturn at +0.7. Through the telescope, however, Saturn will appear larger; its diameter will be 14.72 seconds of arc, while Mercury's will be only 5.7 seconds. Mercury presents a 3/4 gibbous phase on the conjunction date.

By the 27th, Mercury should be fairly easy to find; if you're still having trouble, the planet will be only 0.1 degree south of Regulus (the brightest star in the constellation Leo) on that date. Mercury will be the brighter of the two; its magnitude of +0.1 will outshine Regulus' +1.36. If you know about where Regulus should be by the end of July, you can find Mercury close by without trouble.

Venus

The brightest object in the morning sky, Venus dominates the predawn east for about three hours before sunrise. It shines at magnitude -3.7 for most of July — slightly less bright than it was earlier in the year, but still prominent. Now moving away from Earth, Venus' distance from us increases during July from 77 million miles (124 million kilometers) to 98 million miles (158 million kilometers). Its apparent diameter diminishes from 20.3 to 16 seconds of arc, while its phase grows from slightly more than half lit to almost 3/4 illuminated.

On July 12, the moon passes only one degree south of Venus; observers in southern Africa will be able to witness an occultation of the planet. Elsewhere, the moon will miss covering Venus, but the sight of the crescent moon close by the brightly shining planet is a lovely one, not to be missed. Three days later, Venus passes three degrees north of Aldebaran, the brightest star in the constellation Taurus (now reappearing in the morning sky).

On the morning of July 30, Venus and Jupiter will be separated by only 1.6 degrees. Venus will be much the brighter, but Jupiter, at magnitude -1.6, holds its own; this will be a more equally matched conjunction than the Venus/Mars pairing of May and June. Jupiter will be nearly twice as large as the gibbous Venus through the telescope. Even if you're not usually an early riser, be sure not to miss this meeting in the morning sky of the two brightest planets!

Mars

The red planet is becoming brighter and more prominent in the morning sky with each passing month. July finds it located just west of Venus in the constellation Taurus, with a magnitude of +1.2. Currently approaching Earth as it moves toward opposition early in 1978, Mars' distance changes from 168 million miles (270 million kilometers) at the beginning of the month to 156 million miles (251 million kilometers) on July 31. Its apparent diameter grows during the same interval from 5 to 5.6 seconds of arc.

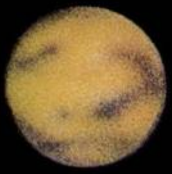
On July 11, look for Mars just two degrees north of the crescent moon. Later in the month, Mars will move past the northern edge of the Hyades cluster; on Aug. 1, it will lie five degrees north of the red star Aldebaran. The star (magnitude +0.86) will be slightly brighter than Mars; this is a

Opposite, top and center: These four slides illustrate the progress of the partial lunar eclipse of April 3. The photo at top left was taken at 10:40 p.m. CST; that at top right was obtained at 11:00 p.m. CST. Mideclipse occurred at 11:18 p.m., when the slide at center left was taken, and the moon was emerging from shadow at 11:35 (center right). All four pictures are 1/125 second exposures on High Speed Ektachrome, obtained with an eight inch Schmidt-Cassegrain. Photographs by Stanley M. Englund. Bottom: These two constellation photos are among a series taken on Feb. 23; both are 15 second *exposures on GAF 500, taken with a 50mm* lens at f/1.8. The constellations pictured here are Gemini (left) and Canis Major. Photographs by Scott Keppler.

Planet Finder

Ⓒ Ceres

July	1	15
R.A.	12h32m	12h45m
Dec.	+6°08'	+3°40'
Mag.	+8.0	+8.3



Ⓐ Mercury

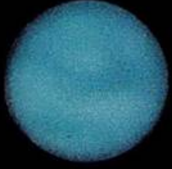
July	1
R.A.	6h54m
Dec.	+24°19'
Mag.	-1.8

Ⓑ Mercury

July	15
R.A.	8h52m
Dec.	+19°15'
Mag.	-0.5

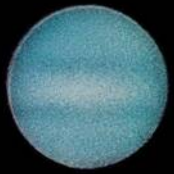
Ⓜ Mars

July	1	15
R.A.	3h06m	3h47m
Dec.	+16°39'	+19°15'
Mag.	+1.2	+1.2



Ⓝ Neptune

July	15
R.A.	16h50m
Dec.	-20°56'
Mag.	+7.7



SUN

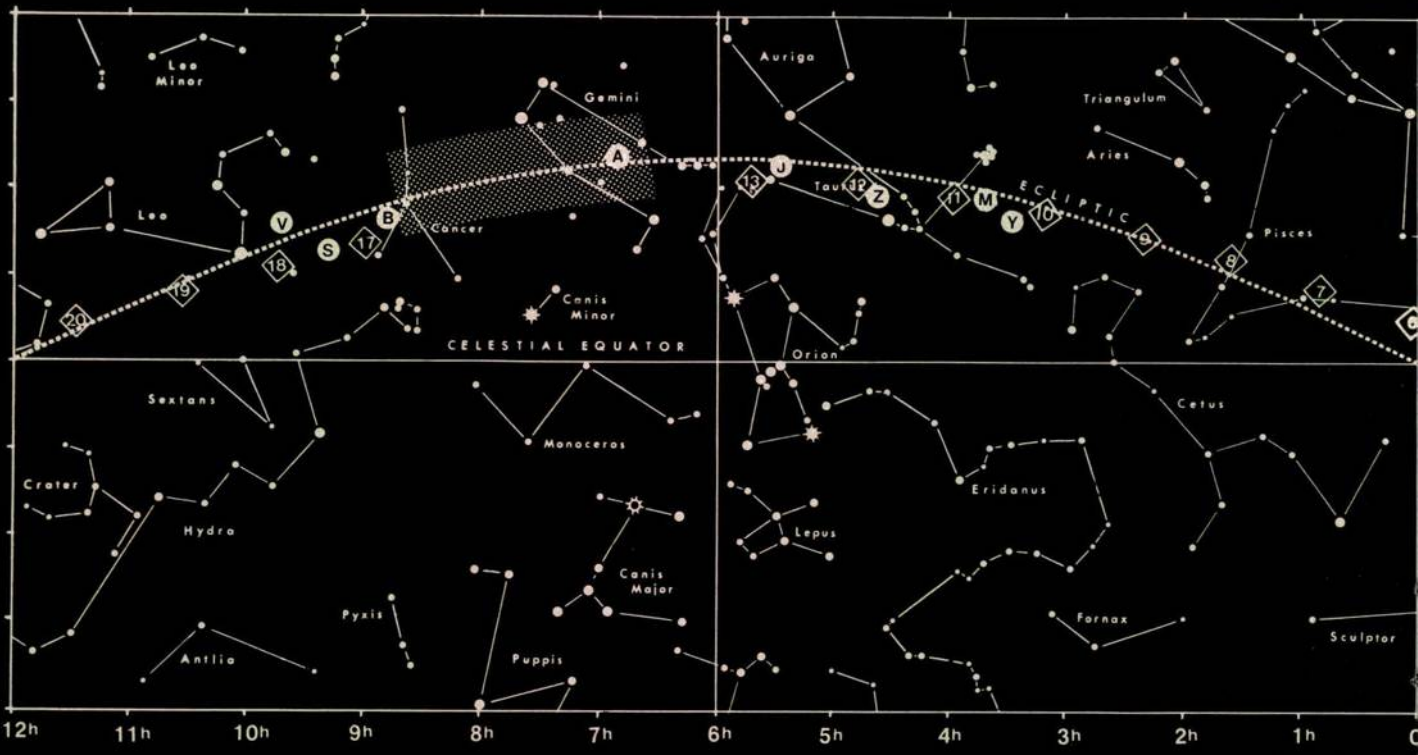
The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

Ⓢ Saturn

July	1	15
R.A.	9h11m	9h18m
Dec.	+17°12'	+16°43'
Mag.	+0.7	+0.7

Ⓤ Uranus

July	15
R.A.	14h21m
Dec.	-13°40'
Mag.	+5.7


Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
A
J
13
Taurus
12
Z
11
M
Y
10
ECLIPTIC
9
8
7
C
Pisces
V
B
S
17
18
19
20
Cancer
Canis Minor
CELESTIAL EQUATOR
Orion
Sextans
Monoceros
Cetus
Crater
Hydra
Eridanus
Lepus
Canis Major
Pyxis
Fornax
Sculptor
Antlia
Puppis
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec. = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag. = magnitude, a

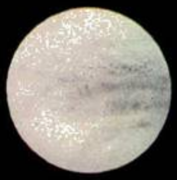
July 1977

Ⓥ Vesta

July	1	15
R.A.	$9^{h}20^{m}$	$9^{h}46^{m}$
Dec.	+19°46'	+17°51'
Mag.	+8.6	+8.6

Ⓙ Jupiter

July	1	15
R.A.	$5^{h}16^{m}$	$5^{h}29^{m}$
Dec.	+22°36'	+22°49'
Mag.	-1.5	-1.5



Ⓨ Venus

July	1
R.A.	$3^{h}33^{m}$
Dec.	+16°14'
Mag.	-3.8

Ⓩ Venus

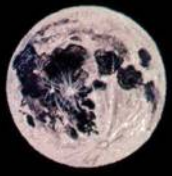
July	15
R.A.	$4^{h}35^{m}$
Dec.	+19°25'
Mag.	-3.7

Ⓟ Pluto

July	15
R.A.	$13^{h}07^{m}$
Dec.	+11°09'
Mag.	+14

First Quarter

July 23

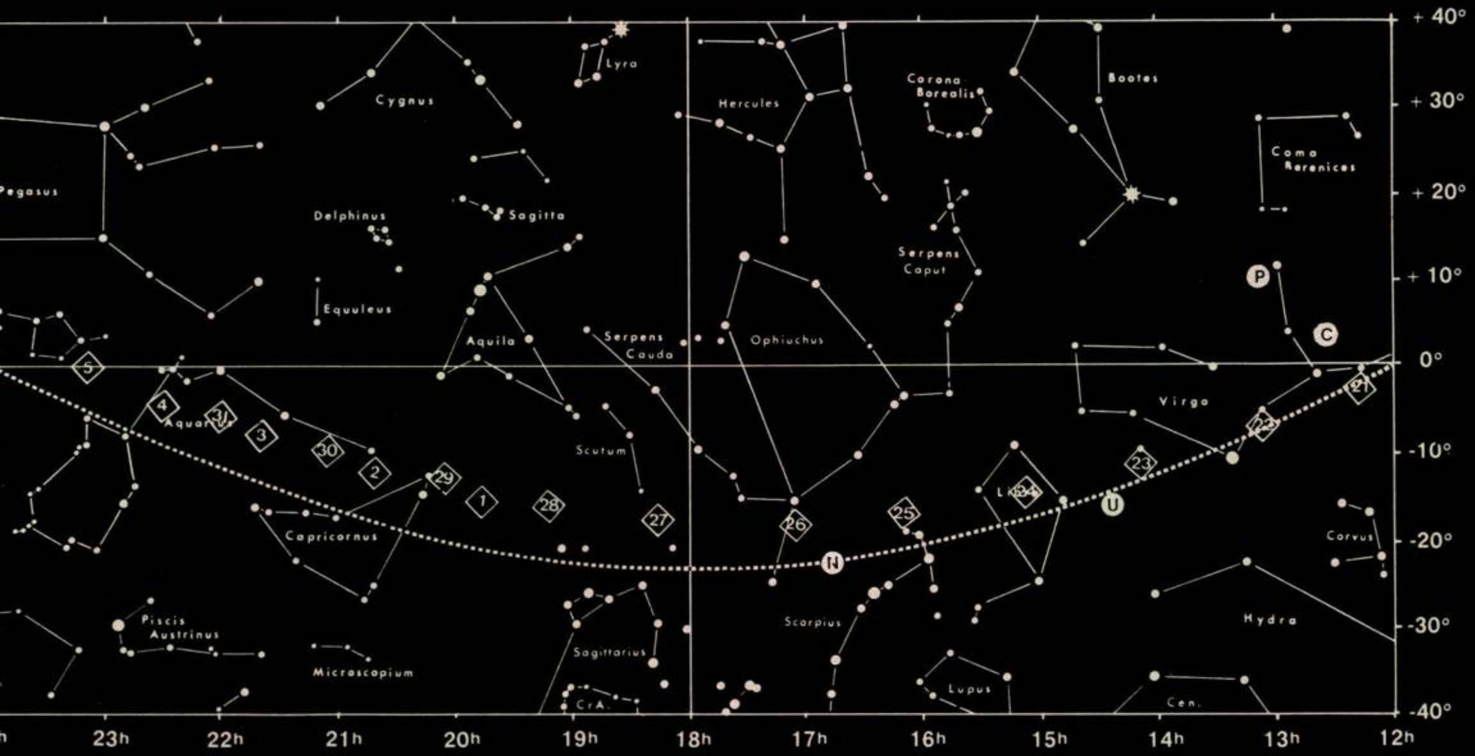


Full Moon

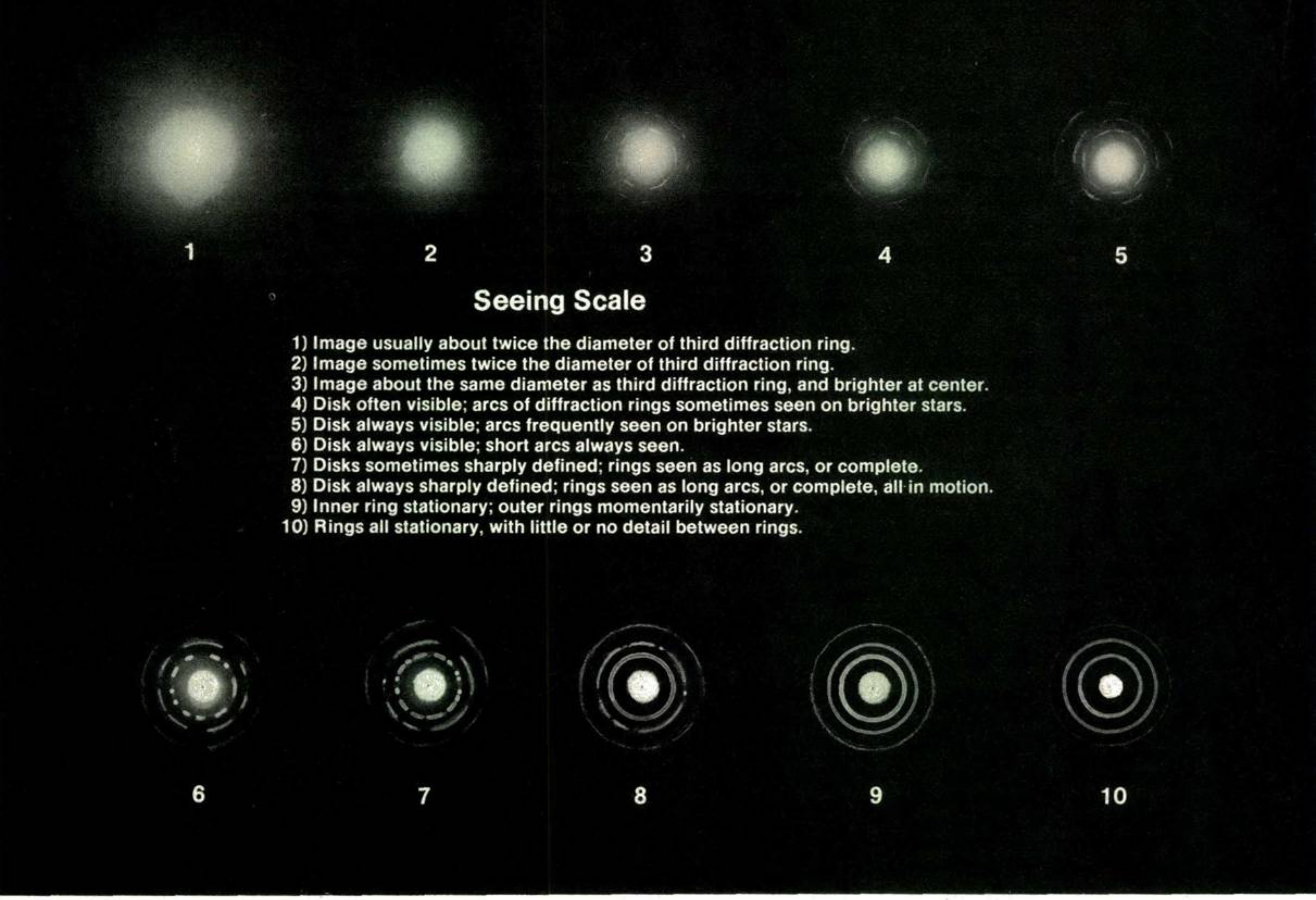
July 30

Last Quarter

July 8


Lyra
Cygnus
Hercules
Corona Borealis
Bootes
Coma Berenices
Pegasus
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Scorpius
Hydra
Piscis Austrinus
Sagittarius
Microscopium
Lupus
CrA.
Cen.
P
C
U
N
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h
1
2
3
4
5
22
23
24
25
26
27
28
29
30
31

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.



Seeing Scale

1) Image usually about twice the diameter of third diffraction ring.
2) Image sometimes twice the diameter of third diffraction ring.
3) Image about the same diameter as third diffraction ring, and brighter at center.
4) Disk often visible; arcs of diffraction rings sometimes seen on brighter stars.
5) Disk always visible; arcs frequently seen on brighter stars.
6) Disk always visible; short arcs always seen.
7) Disks sometimes sharply defined; rings seen as long arcs, or complete.
8) Disk always sharply defined; rings seen as long arcs, or complete, all in motion.
9) Inner ring stationary; outer rings momentarily stationary.
10) Rings all stationary, with little or no detail between rings.

good opportunity to compare these two objects, closely matched in color.

Jupiter

On the other side of Venus from Mars, Jupiter emerges from the predawn twilight this month to resume its place as a prominent object in the morning sky. As it moves closer to Earth — from 560 million miles (900 million kilometers) on July 1 to 540 million miles (870 million kilometers) on the 31st — its angular diameter increases from 30.5 to 31.6 seconds of arc, and its brightness grows from magnitude -1.5 to -1.6.

Look for Jupiter four degrees north of the thinning crescent moon on the morning of July 13. As the month comes to a close, Venus and Jupiter draw together, and will lie 1.6 degrees apart in the sky on July 30.

Saturn

Saturn is very low in the west at sunset during the evenings of July; it will reach conjunction with the sun on Aug. 13, after which it will join the other planets in the morning sky. Its distance from Earth at the end of the month is 946 million miles (1,520 million kilometers); its angular diameter on that date is 14.6 seconds of arc, and its magnitude is +0.6.

Saturn lies six degrees north of the moon (two days past new) on the 18th; the next day it will be in conjunction with Mercury, 0.4 degrees south of that planet. Look for the two together in binoculars or a low power telescope eyepiece.

Asteroids, Meteors

Among the asteroids that reach opposition in July are 8 Flora and 17 Thetis. The latter is at opposition on July 25 in the constellation Capricornus, at right ascension $20^{h}12^{m}$ and declination -19°13'; its magnitude is 10. See Gazer's Gazette for more information on observing Flora and asteroids in general.

The nearly full moon should interfere strongly with observation of the Delta Aquarid meteor shower, which reaches its peak about July 29. The Delta Aquarids are a straggling shower that span a period of about two weeks. Despite the moonlight, however, you may want to try watching for them — if for no other reason than to practice for the Perseid shower. The Perseids, the most reliable meteor shower, will peak in early August.

Scales of Seeing

Veteran observers and astrophotographers know that the visibility of planetary surface detail, or the limit of double star resolution, depends to a great extent on what is commonly called "seeing". Turbulence at different levels of the atmosphere can produce ill effects for the ground based telescope user; the illusion of a seemingly perfect night for observing can be shattered by a glance through the telescope and the discovery that a planet's image is so distorted by poor seeing conditions as to render observation useless. Planetary photographers, especially, need to be able to judge the "seeing" before attempting any worthwhile photos. Different scales of "seeing" have therefore been devised to allow the observer to rate the night's sky condition.

The scale given on this page is a classic 10 point seeing scale devised by the famous observer W.H. Pickering from his work with a five inch refractor. It describes the appearance of a bright star's disk and diffraction rings through the telescope.

When using this scale, remember that conditions can change over the course of a night, and what may begin as a poor evening for stargazing may later turn out to be good after all — especially since there's generally more turbulence in the air immediately after sunset than later in the night, as the ground gives off the heat it has absorbed during the day.

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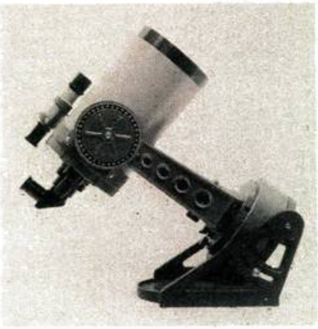

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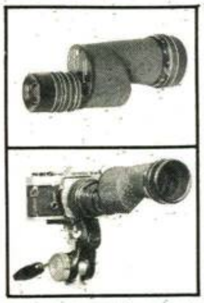

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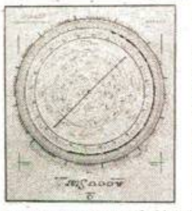

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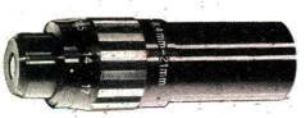

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Norman J. Boisclair Rensselaer, New York

I appreciate the fast shipment of the 20mm Research-Grade Erfle, which was in my hands 4 days after I mailed the order! I would also like to say that the eyepiece is the finest I have ever used, borrowed or seen, and I have seen many in the 15 years I have been an amateur. In the future I intend to convert my battery of eyepieces to Meade Research-Grade orthoscopics, the sooner the better.

Jim Schultz Lyons, Colorado

Let me mention how pleased I am with your products and the very prompt service I have received. I am especially excited with your Research-Grade 20mm Erfle. Its incredible field of view and flatness of field make it perfect for my variable star work. It is truly breathtaking with deep-sky objects. The real surprise came when coupled with your Research-Grade 2X Telenegative Amplifier . . . truly a fine optical achievement.

James L. Ferreira Fremont, California

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Multi-Coated • Parfocal • Threaded for Filters

Orthoscopic 4, 7, 10.5, 16.8, 28mm . . . each	$ 29.95 ppd.
Erfle 20mm.	36.50 ppd.
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Set of any 4 Orthoscopics plus Erfle 20mm, with case	137.50 ppd.
Full set of 5 Orthoscopics plus Erfle 20mm, with case	165.00 ppd.

Rack-and-Pinion Focusers - Three superbly engineered focusers. Thousands in use by amateurs everywhere. *See Items #21, 22, 23.*

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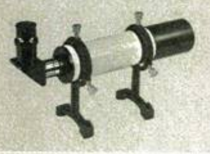
2" O.D. Eyepieces - *See Items #10, 11.*

8 x 50 Right-Angle Viewfinder

With new Kellner 30mm Extra-Wide-Field crosshair eyepiece. *See Item #31.*



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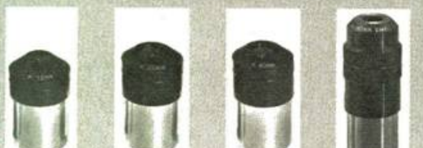

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2x-3x Telenegative Amplifiers - The world's finest Barlow lenses, 26mm clear aperture, 1¼" O.D. *See Items #16, 17.*

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12 - ERFLE 32mm (1-1/4" O.D.) - As in (10), but with standard 1-1/4" barrel, threaded for our filters. 60° field...**$67.50.**

13 - .965" EYEPIECES - (phone, or request catalog, for details).

14 - ILLUMINATED RETICLE GUIDING EYEPIECE (1-1/4" or .965" O.D.) - For professional-level photographic guiding. Kellner 12mm optical system, with precisely focusable 4-line glass reticle. Remote brightness control and 3 ft. cable. (Extension cables available) Complete...**$37.50 ppd.**
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15 - 2X ACHROMATIC BARLOW LENS (1-1/4"O.D.) - A high resolution, coated, negative achromat with excellent corrections for spherical and chromatic aberrations. **$18.75 ppd.**

16, 17 - 2X AND 3X TELENEGATIVE AMPLIFIERS (1-1/4" O.D.) - The world's finest Barlow lenses. Full 26mm clear aperture, with virtually flawless optical corrections at all photo-visual wavelengths. Produces optimum performance on telescopes of any focal ratio. Fully coated. (16) **2X Model 122...$29.50 ppd.** (17) **3X Model 123...$32.50 ppd. - Combination 2X and 3X Model 124...$39.50 ppd.**

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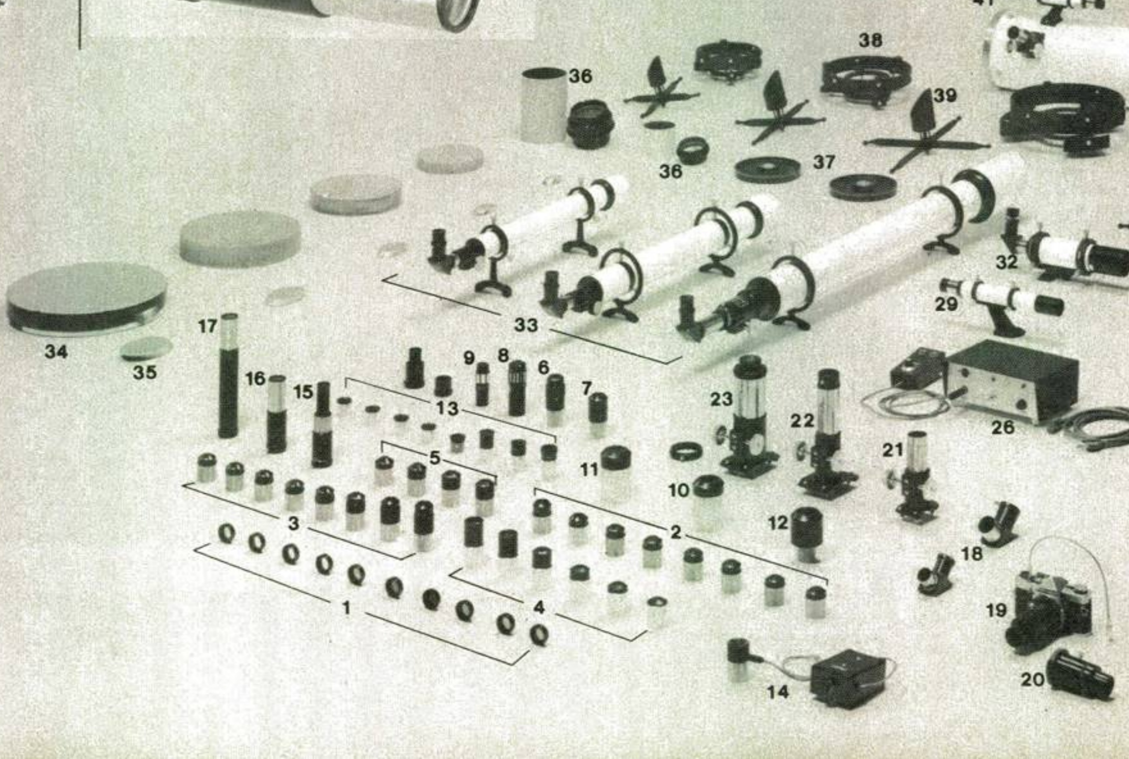

20 - DELUXE CAMERA ADAPTERS - Adapt your camera to telescope focuser instantly. Individually machined from solid bar aluminum. All units permit both eyepiece projection and first (prime) focus photography. Specify either .965'' or 1-1/4'' focuser. (If for Celestron, please specify.) All 1-1/4'' units are threaded for our filters. **Pentax, Praktica, Yashica, Mamiya...$15.95 ppd. - Exakta, Nikon, Canon, Minolta, Miranda, Konica...$23.95 ppd. - Olympus OM-1...$24.95 ppd.**

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22 - Model #640 - A heavy-duty deluxe focuser for 6'' to 16'' telescopes. Full 3'' travel for both visual and photographic applications...**$21.75 ppd.**

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ACCESSORY CASES - Rugged polyethylene, for dust-free protection of eyepieces, filters, Barlows, etc. For either 1-1/4'' or .965'' accessories. Die-cut foam lining.
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31 - 8 x 50mm Right-Angle - 50mm aperture, for both straight-through and right-angle viewing. Prism included...**$30.95 ppd. - Brackets: $7.95/Pr.**
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38, 39 - MIRROR CELLS AND SPIDERS/DIAGONAL HOLDERS are available to fit the tubing below. Phone, or request catalog, for details.

40 - FIBERLITE TELESCOPE TUBES - 20% more rigid, yet 40% lighter, than pure fiberglass, with low thermal conductivity. Polished end rings available at nominal cost. Partial price list: **7'' I.D. x 50''...$36.00 - 9-1/4'' I.D. x 60''...$49.50 12-3/8'' I.D. x 62''...$68.00 - 12-3/8'' I.D. x 72''...$76.00**
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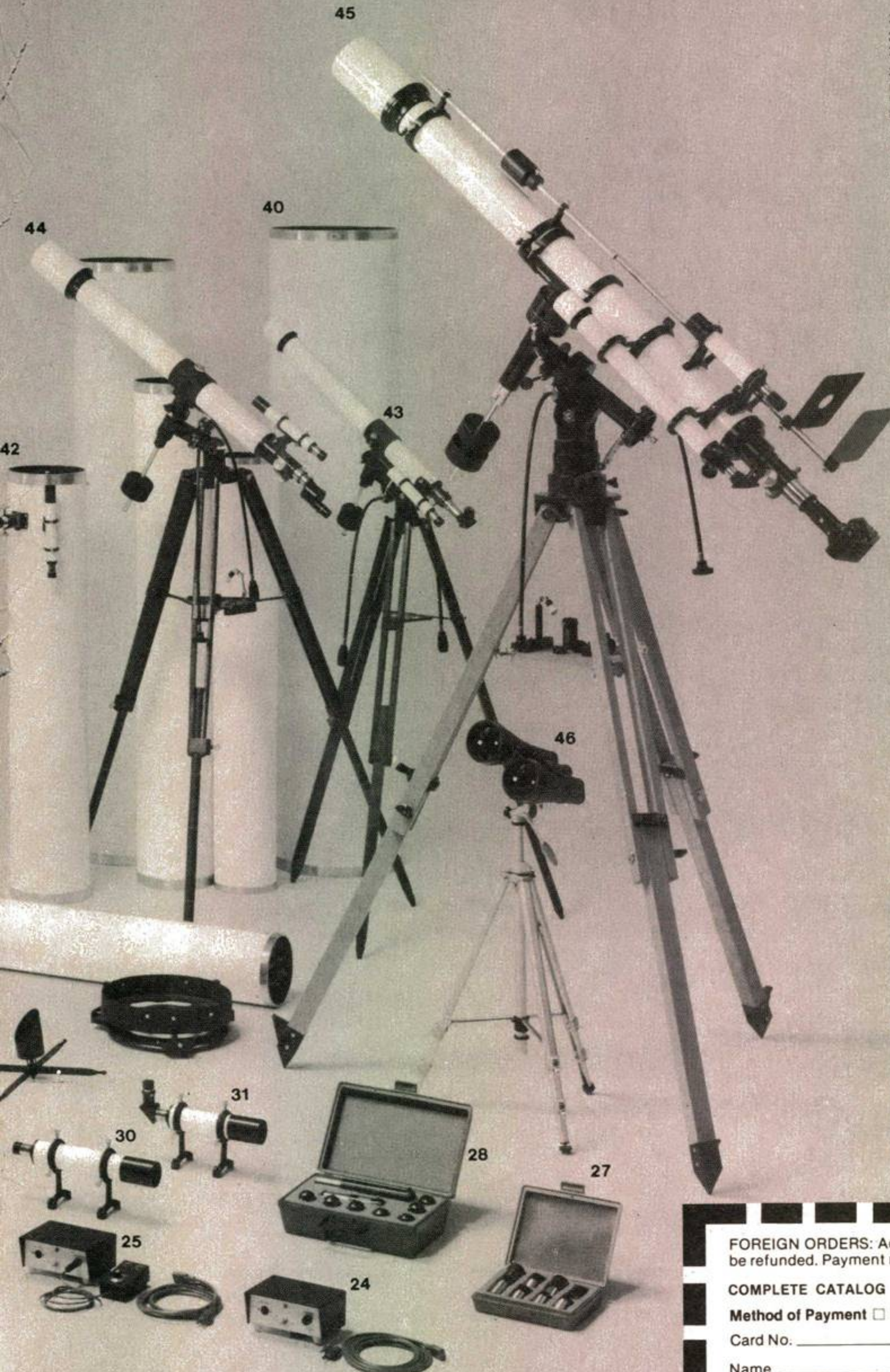
COMPLETE OPTICAL TUBE ASSEMBLIES - Fully Assembled. Each assembly includes the premium quality Meade components described above: Fiberlite tube with end rings, primary mirror and cell, spider and secondary mirror, Model #67 Focuser, 6 x 30mm viewfinder. Shipping charges collect.
41 - 6'' f/8 tube assembly...$144.95
42 - 8'' f/6 tube assembly...$189.95
Packing charge on tube assemblies...$6.00

MEADE EQUATORIAL REFRACTORS - Whether beginning or serious amateur, one of these superb instruments will fit your observing requirements. Phone or request catalog for details.
43 - Model #291: 2.4'' Equatorial Refractor...$195.00
44 - Model #300: 3.1'' Equatorial Refractor...$325.00
45 - Models #420 - #440: 4'' Equatorial and Photo-Equatorial Refractors, available with guide telescope, illuminated reticle eyepiece, motor drive, frequency corrector, astrocamera. **From $1175.00**
Equatorial Mounts - Each includes complete mount, circles, 2 cables, hardwood tripod. **Mount for Model #291...$95.00 - Mount for Model #300...$157.00**

46 - 20 x 80mm ASTRONOMICAL BINOCULARS - Coated optics. Magnificent for deep-space observing...**$127.50 ppd.**
Bushnell Tripod: fully adjustable...**$49.50 ppd.**



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GAZER'S GAZETTE

TRACKING ASTEROIDS

by
Frederick Pilcher and Jay Gunter

For many years, asteroids were almost completely neglected by observers. This lack of interest apparently stemmed from the idea that asteroids are very difficult to observe — a statement often made in older astronomy books. The reason for this difficulty is the small size of asteroids: *All* minor planets are so tiny that they show starlike images in any but the largest telescopes. Thus, it can be hard to decide which of a number of objects near an asteroid's predicted position is the object sought.

A tracking chart that shows all stars to a magnitude somewhat fainter than the asteroid's solves the problem. The increased availability and use of such charts has recently led to a boom in asteroid observing. Many observers now have dozens of asteroids on their personal records — and a few have seen hundreds! In the field of a telescope, an asteroid will really stand out by its absence on the tracking chart. You can usually identify the asteroid immediately, and you can also detect its movement — often within a few hours, and always by the following night.

Ideal star atlases for asteroid tracking are Hans Vehrenberg's **Atlas Falkau** or **Atlas Stellarum**, which show stars to magnitudes 13 and 14, respectively. Besides a good chart, you'll also need the asteroid's *ephemeris* (its right ascension and declination on different dates). The ephemerides of every numbered asteroid at 10 day intervals are published in the annual **Ephemerides of Minor Planets**, prepared by the Institute for Theoretical Astronomy in Leningrad, Russia.

For your first asteroid, be sure to select one that is well within your telescope's magnitude limit. On a thin sheet of paper, use the coordinate grid included with the Vehrenberg atlas to mark (with small crosses) the position of the asteroid at 10 day intervals.

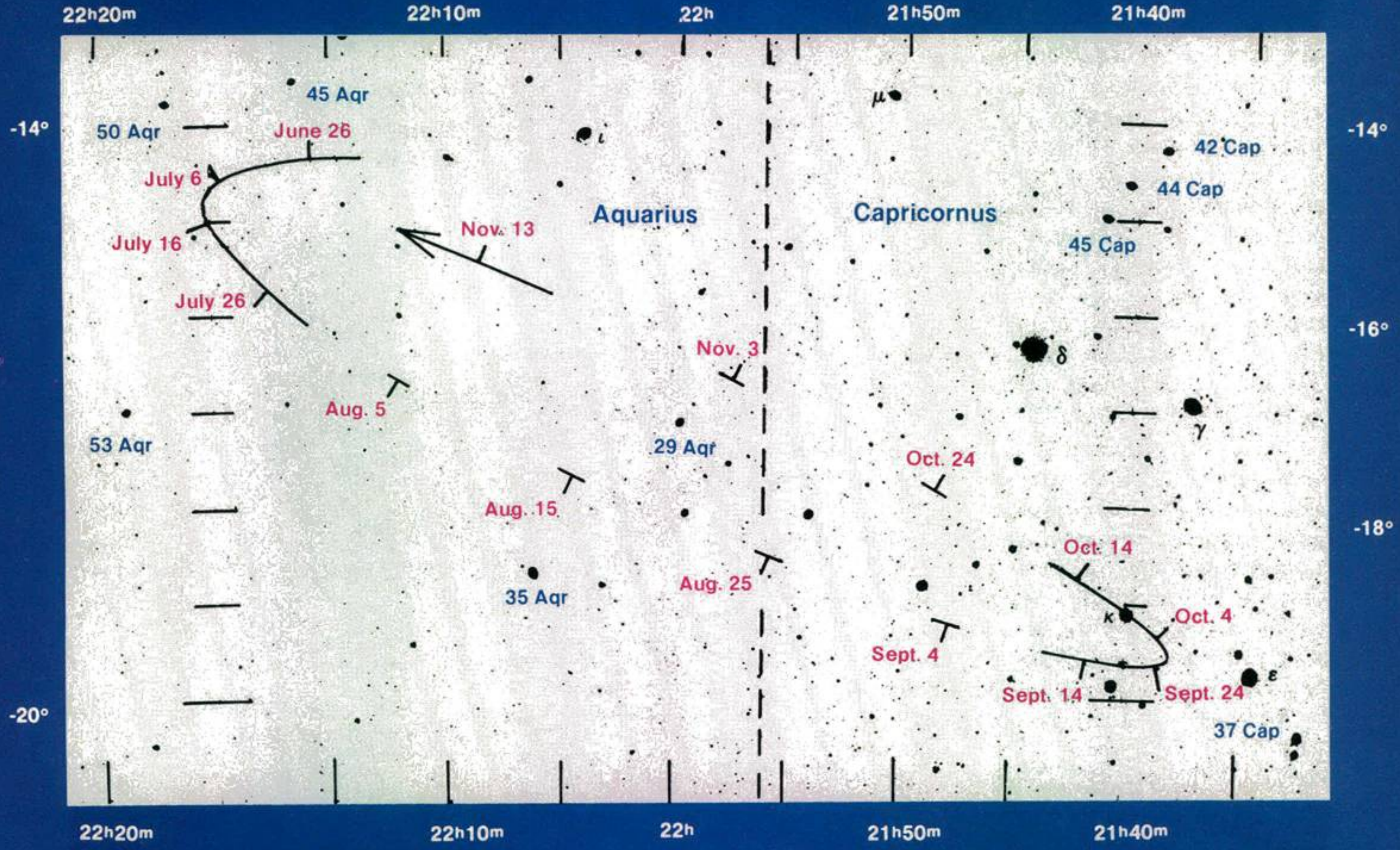
Carefully align the center coordinates of this tracking sheet with those on the correct sheet from the Vehrenberg atlas, and hold both sheets in place on a clipboard. (Be sure alignment is precise!) Illuminate the sheets from beneath with a flashlight. Find the field in your telescope; at the predicted place a starlike object *not shown on the star atlas* should appear. You have found your asteroid!

Mark the asteroid's position on the tracking sheet with a dot. As you observe again the follow-

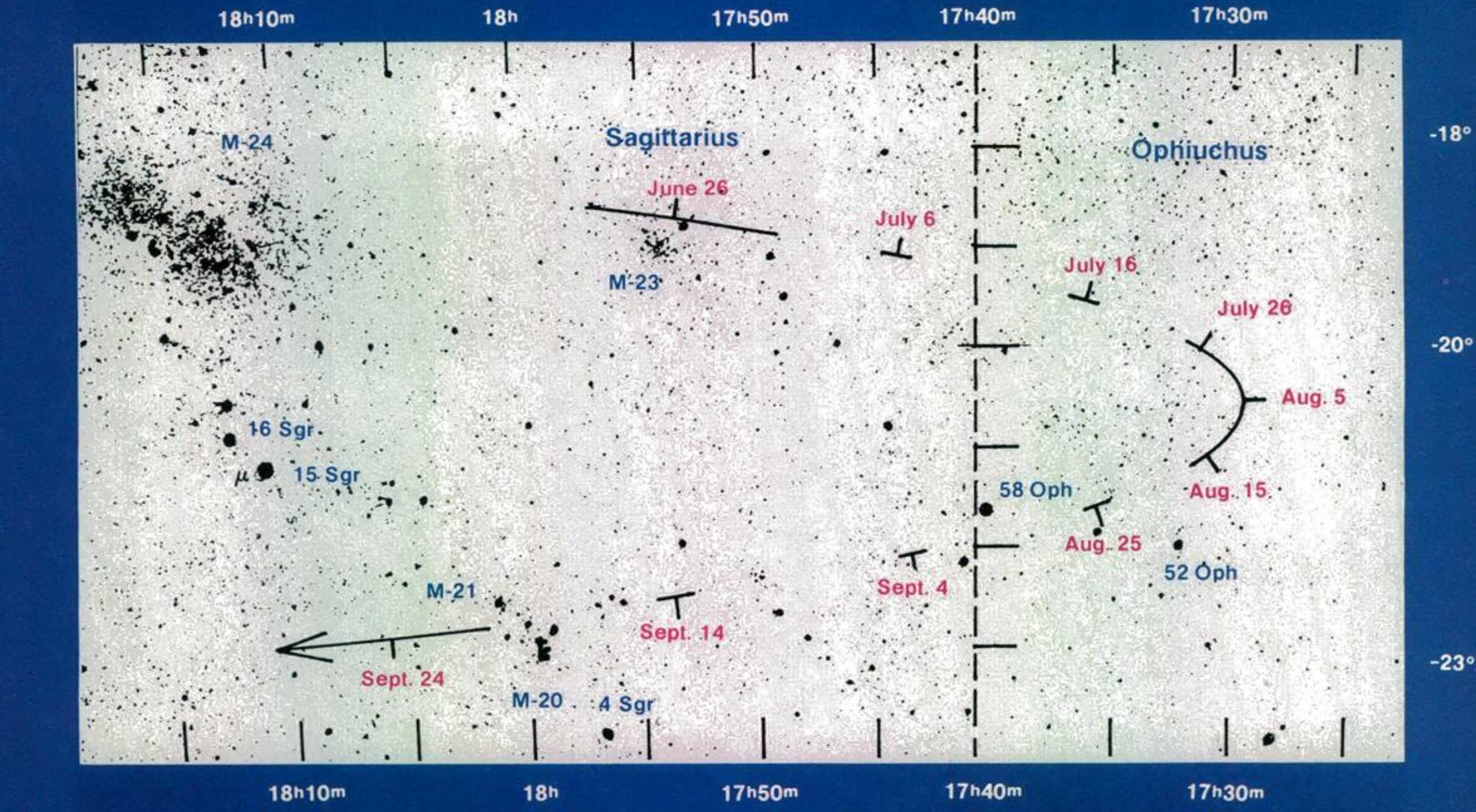
Asteroid 21 Lutetia is at opposition on Aug. 21 at visual magnitude 9.5 and at a distance of about 97 million miles from Earth. Note the very close appulse and possible occultation of Kappa Capricorni on Oct. 8. Lutetia, found on Nov. 15, 1852, was the first of 14 asteroid discoveries by Hermann Goldschmidt. The star field (limiting magnitude about 12.5) is taken from Hans Vehrenberg's Photographic Star Atlas, Plates 264, 265, 300 and 301, and is reproduced courtesy of Dr. Vehrenberg. Map by Jay Gunter.

Asteroid 11 Parthenope was at opposition on June 21 at a visual magnitude of 9.3; its distance was about 118 million miles from Earth. Note its proximity to M-23 on June 26 and its passage between M-20 and M-21 on Sept. 19. Parthenope was discovered by Annibale De Gasparis in Naples on May 11, 1850. The star field (with a limiting magnitude of about 12.5) is from Hans Vehrenberg's Photographic Star Atlas, Plates 294 and 295, and is reproduced courtesy of Dr. Vehrenberg. Map by Jay Gunter.

Opposition of Lutetia


22h20m
22h10m
22h
21h50m
21h40m
-14°
-16°
-18°
-20°
45 Aqr
50 Aqr
June 26
July 6
July 16
July 26
Nov. 13
Aquarius
Capricornus
μ
ι
42 Cap
44 Cap
45 Cap
Nov. 3
δ
γ
Aug. 5
53 Aqr
29 Aqr
Oct. 24
Aug. 15
Oct. 14
35 Aqr
Aug. 25
κ
Oct. 4
Sept. 4
Sept. 14
Sept. 24
ε
37 Cap

Opposition of Parthenope


18h10m
18h
17h50m
17h40m
17h30m
-18°
-20°
-23°
M-24
Sagittarius
Ophiuchus
June 26
July 6
July 16
July 26
M-23
Aug. 5
16 Sgr
μ
15 Sgr
58 Oph
Aug. 15
Aug. 25
52 Oph
Sept. 4
M-21
Sept. 14
Sept. 24
M-20
4 Sgr

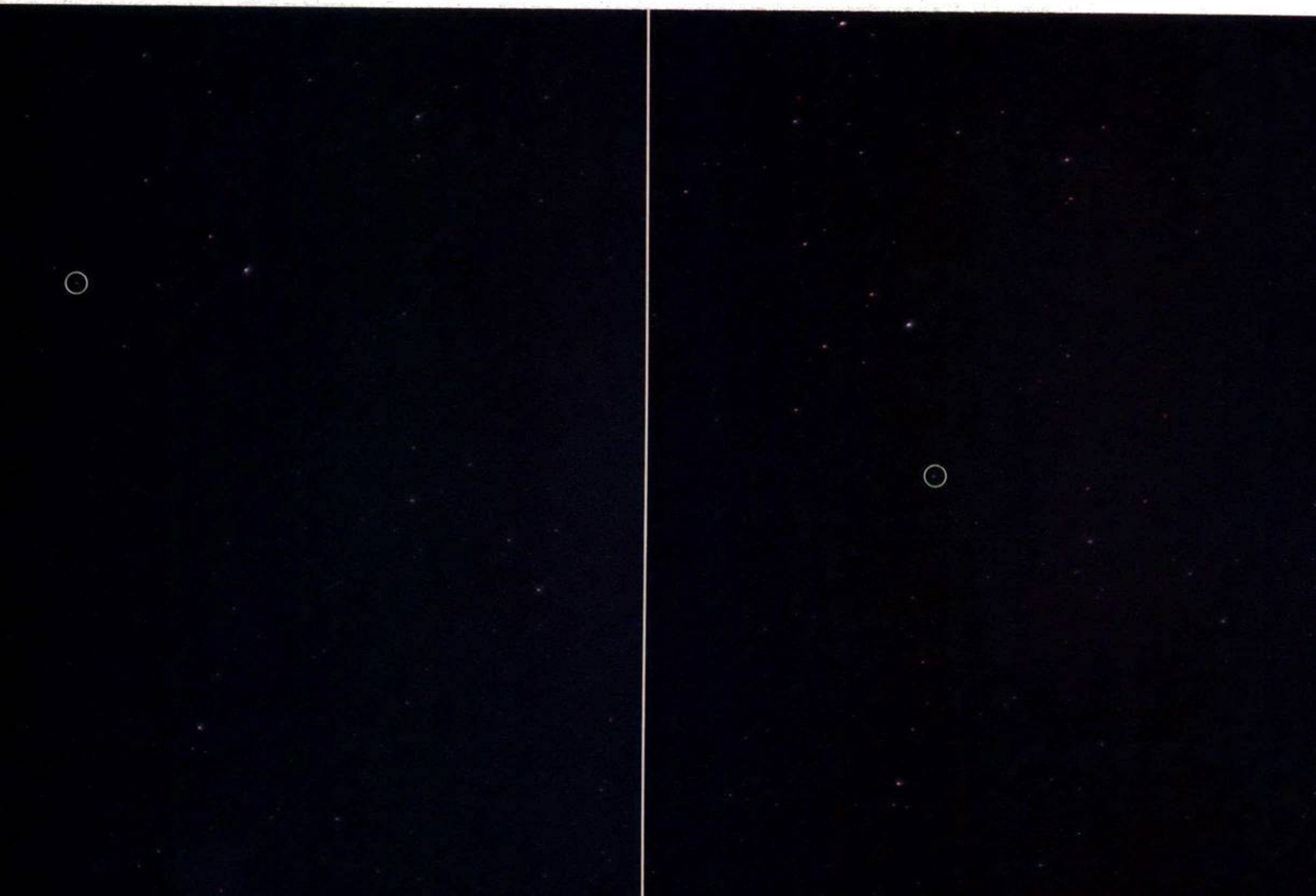
ing nights, plot each position — along with the time of observation — as the asteroid moves along. When you have good star charts, asteroid tracking becomes nearly as easy as locating faint deep sky objects, and experienced observers can often find as many as 10 asteroids per hour. When you're just starting out, of course, your average will be less. But don't give up — persistence will pay off!

Some observers prefer to copy the Vehrenberg atlas charts, plotting the asteroid positions directly onto the copies. The advantage of this is that the trouble of precisely aligning two sheets is eliminated. But watch out for a change of scale in the copy process. Even a small change of scale will cause positions that are plotted with the original coordinate grid to be in error — enough to make the asteroid very hard to find.

It is mandatory that you make more than one observation of each asteroid! Even experienced asteroid observers occasionally misidentify an object, confusing the asteroid with a nearby star. A second look a few hours or days later may reveal that the object so confidently identified as an asteroid has not moved after all — and you'll have to start over. You must observe each asteroid at least twice (and more often if possible) in different places. Its absence from the location of the previous observation must be confirmed for you to be sure you've identified it correctly. If circumstances (such as clouds) do not permit a second observation, the singly-observed object should be removed from the records. You will only be fooling yourself — and anyone to whom you report your finding — if you don't make a second confirming observation.

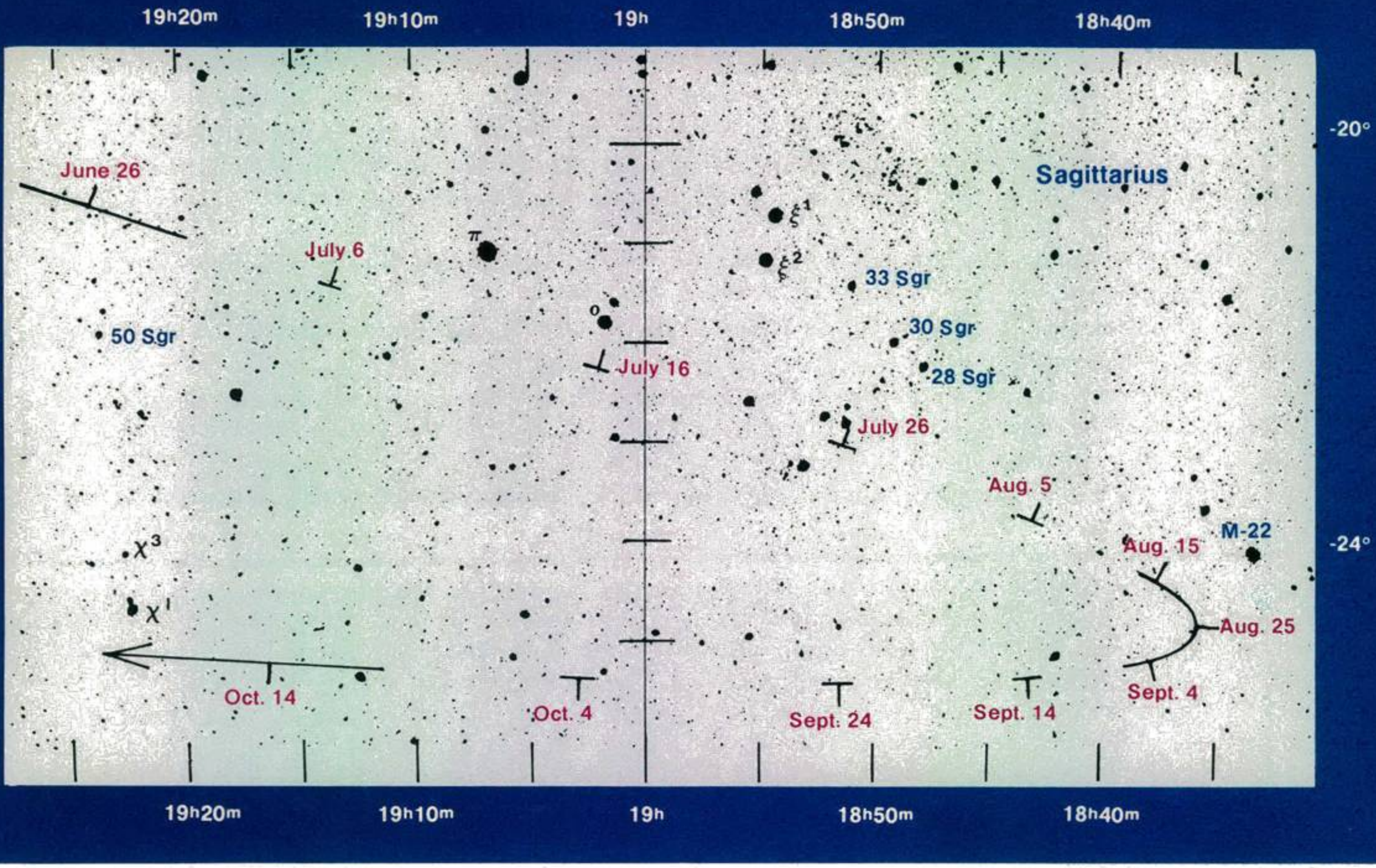
Tracking asteroids requires the technique of star hopping on charts, and asteroid observation is more challenging than telescopic observation of naked eye objects. No exercise more completely welds the observer, his telescope, and his charts into an efficiently functioning team.

Like the planet Mars, asteroids are at their brightest and are most easily observed when they're near opposition. Except for a few of the brightest and some with unusual orbits, asteroid ephemerides are published only for ten day intervals centered at opposition. You might be able to catch faint asteroids near your telescope's limit for only a few days before and after opposition. Also, asteroid observing is impossible when the moon is within a few days of full (as are most types of observing); the moon's



Asteroids aren't difficult to photograph, and two pictures taken weeks apart will easily show an asteroid's motion. Left: Ceres was at magnitude 6.7 on April 18, when this photo was taken. Right: By May 7, it had moved to the position shown in this photo, and had faded slightly to magnitude 6.9. Both photos are eight minute exposures on Fujichrome-100, made with a 135mm lens at f/2.8. Photographs by L.H. Price.

Opposition of Flora



Asteroid 8 Flora is at opposition on July 9 at visual magnitude 8.9, and at a distance of about 116 million miles from Earth. Note its position not far from M-22 during mid-August. Flora was found on Oct. 18, 1847, the second of 10 minor planet discoveries by John Russell Hind. The star field is taken from Hans Vehrenberg's Photographic Star Atlas, Plates 295, 296 and 297, and is reproduced courtesy of Dr. Vehrenberg. Map by Jay Gunter.

glare — especially when it's near opposition — drowns out the faint light of asteroids.

In the annual ephemeris volumes, the published magnitudes are in the photoelectric B (blue) system. Visually, asteroids are 0.7 to 0.9 magnitudes brighter, due to the spectral distribution of sunlight. The opposition magnitudes of the asteroids plotted in the charts on pages 43 and 45 are corrected from photographic to visual by subtracting 0.8 magnitude. The actual magnitudes will be fainter than the published opposition magnitudes by about 0.1 magnitude for every week by which the observation is removed from the opposition date. When attempting to find asteroids near the limit of your telescope, you should use higher magnifying powers, which spread out the background light of the sky. Fainter objects can be seen against this darker background as long as the seeing is good and the asteroids remain point sources.

At any time except near full moon, there will be at least one — and usually several — asteroids within easy reach of a four inch telescope. On pages 43 and 45 are tracking charts for three asteroids observable in this summer: 8 Flora, 11 Parthenope and 21 Lutetia. The positions of these have been plotted at 10 day intervals on appropriate charts taken from **Atlas Falkau.** Once your enthusiasm is stimulated by successful observations of these asteroids, you may want to borrow or buy a set of Vehrenberg charts and the annual ephemeris volume. Many other asteroids nearly as bright are awaiting observation.

With a four inch telescope and fairly good skies, it should be possible over a period of several years to observe about 200 different asteroids. With a 12 inch instrument, you may see up to 800! Remember, though, that dedication and perseverance will be necessary, and you should make observations as often as you can.

Many asteroids have orbits with large eccentricity, and (like Mars) are much brighter at near-perihelion oppositions than at others. These will be near their maximum possible brightness only at intervals of many years, and then only for a few short weeks. It therefore takes many years to find all the asteroids that are within reach of a given instrument.

Once you've spent a fair amount of time at asteroid hunting, you can make extremely useful contributions to the study of asteroids when you report your observations to the proper organization — in this case, Association of Lunar and Planetary Observers (ALPO). Great opportunities lie in magni-

More Information on Asteroid Observing

Both Frederick Pilcher and Jay Gunter have been observing asteroids for a number of years, and have corresponded with many observers about them. Readers' observational reports, comments and questions may be directed to Frederick Pilcher, Illinois College, Jacksonville, Ill. 62650. Pilcher can also provide assistance in setting up an asteroid photometry program and in reducing the data.

Jay Gunter edits **Tonight's Asteroids**, a free bimonthly newsletter with timely information and detailed tracking charts. Send a long, self-addressed stamped envelope to Jay Gunter, 1411 N. Mangum St., Durham, N.C. 27701.

Derek Wallentine would like to correspond with any observer interested in estimating magnitudes and making light curves of asteroids. His address is 3131 Quincy N.E., Albuquerque, N.M. 87110.

For information on ALPO's **Minor Planet Bulletin**, write Rev. Richard Hodgson, Dordt College, Sioux Center, Iowa 51250.

The North American distributor of **Ephemerides of Minor Planets** is the University of Cincinnati Observatory, Observatory Place, Cincinnati, Ohio 45208. At the time this article was written, supplies were limited — so share copies if you can!

Either of Hans Vehrenberg's atlases may be obtained through Sky Publishing Corporation, Cambridge, Mass. 02138.

tude studies. As asteroids are scarred, pitted, and broken in collisions with smaller bodies, their shapes become irregular. This causes their apparent brightness to change as they present faces of different surface areas toward Earth during their rotation. The period of rotation can be determined by a simple timing of maxima and minima in the light curve. Visual estimates by a skilled variable star observer can be of considerable value here. Many readers may recall the large 1.5 magnitude rotational variation that Eros exhibited as it passed Earth in January 1975. This, however, is exceptional; most asteroids vary by 0.5 magnitude or less, and great care is needed to record these tiny changes. ALPO member Derek Wallentine has prepared extensive lists of asteroids which pass through fields of AAVSO (American Association of Variable Star Observers) variable star charts so that their magnitudes can be compared directly with those of known stars.

Even if an asteroid does not lie in an AAVSO field, you can still measure brightness *changes* by differential photometry, and prepare light curves from such observations. Once you locate the field and asteroid, assign arbitrary but equal steps of brightness (for example, 0 to 20) for several stars ranging from slightly brighter to slightly fainter than the asteroid. Then rate the brightness of the asteroid in reference to these arbitrary steps. For visual photometry the asteroid should be observed at least once every 15 to 20 minutes, for as long a time interval as possible. Usually only a small amount of information can be obtained from a light curve of less than three hours' duration; a light curve of six to eight hours is highly desirable if circumstances permit an all-night run — the longer the better. If such light curves can be made on two or three consecutive nights, the period of rotation can be determined to within a few minutes. Additional light curves at intervals of several days, if continued for several weeks or months, permit the rotation period to be determined to within a few seconds. Such accuracy is currently available for very few asteroids, so you'll get the thrill of breaking new ground.

You can find the approximate position of an asteroid you observe visually by laying a coordinate grid over your tracking chart. Occasionally the published ephemeris may be appreciably in error, with the asteroid several minutes of arc from the predicted position. Approximate positions measured off coordinate grids are useful for alerting other observers to the discrepancy, and in helping them find the errant asteroid. To be of value in orbit computation, however, asteroid positions must be found within *one second of arc* and to the *nearest second of time*. An astrophotographer with first class guiding and WWV time signals (high frequency signals broadcast on the second) can probably obtain photographs with inherent accuracy as good as this — but will still need to measure the positions of the asteroid (and of several of the stars) on his photograph to 0.001mm accuracy. Anyone who can buy, build or borrow a measuring device with this accuracy will compete successfully with professional astrometric photographers.

A number of observers have embarked upon these and other advanced programs. Overall coordination of advanced work is being directed by Rev. Richard Hodgson (of Dordt College in Iowa), and findings are published in the **Minor Planet Bulletin** of ALPO.

Requirements for asteroid observing may seem formidable, but once you've found your first minor planet, you'll want to go on and observe another, then another, and another . . . and so on. There are so many (almost 2,000 have numbers) that you could conceivably go on forever! Why not get started tonight?

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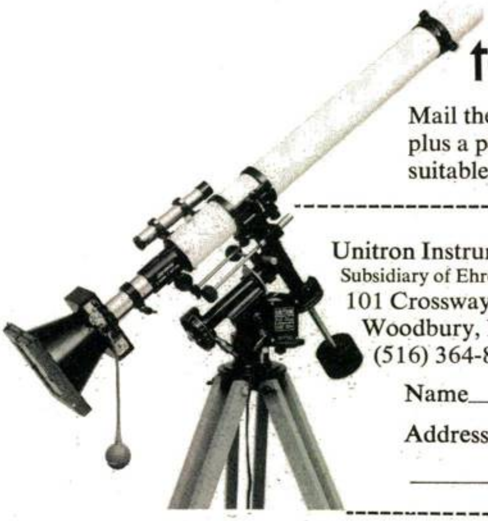

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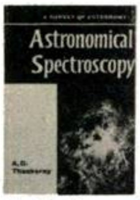

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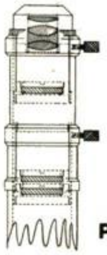

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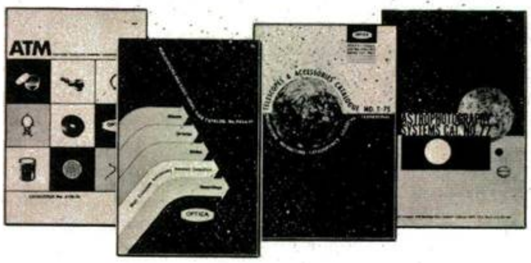

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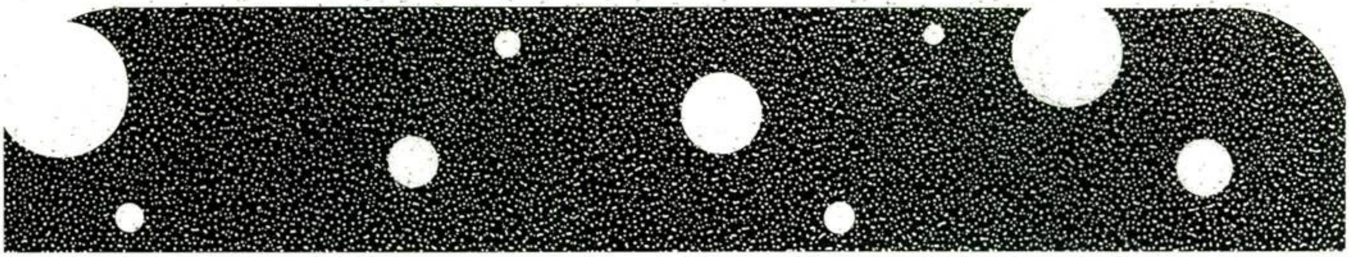


STELLAR FRONTIERS

What Makes Novae Blow Up?

by
Deborah Byrd and Joseph Patterson

There is an old African legend about an elephant graveyard to which all self-respecting elephants hasten before they die. The graveyard is supposed to account for the fact that no one ever finds dead elephants on the plains or in the jungles, but — unfortunately for the legend — no one has ever found the graveyard, either. Unlike the mystery of elephant carcasses, which *should* be prominent but *aren't*, is the fate of some dying stars, which *shouldn't* be prominent but *are*.

Long after such a star's nuclear fires have been quenched and it should be quietly fading into darkness, it will sometimes acquire a new power source and increase thousands to millions of times in brightness. Such a star is called a *nova*. Though not as spectacular or as rare as supernovae, novae puzzle astronomers with their ability to surge in brightness, stay bright for a few days or weeks, and then gradually fade back to normal.

The word "nova" comes from the Latin root meaing "new". Oriental astronomers long ago believed that novae were new stars, or "guest stars" as they called them, because a nova outburst can cause a star to pop into view in a place in the sky that is normally dark. While Eastern stargazers faithfully recorded nova eruptions for centuries, their Western counterparts just as faithfully ignored them. If, as Aristotle had said and the Westerners believed, the heavens were perfect and unchanging, then the addition of new stars was impossible!

Today we know that novae are common in the galaxy. Several large novae are observed each year, and many smaller, recurring novae are systematically watched by the astronomers who study them. Not until recently, however, has significant progress been made in understanding what causes these stellar cataclysms.

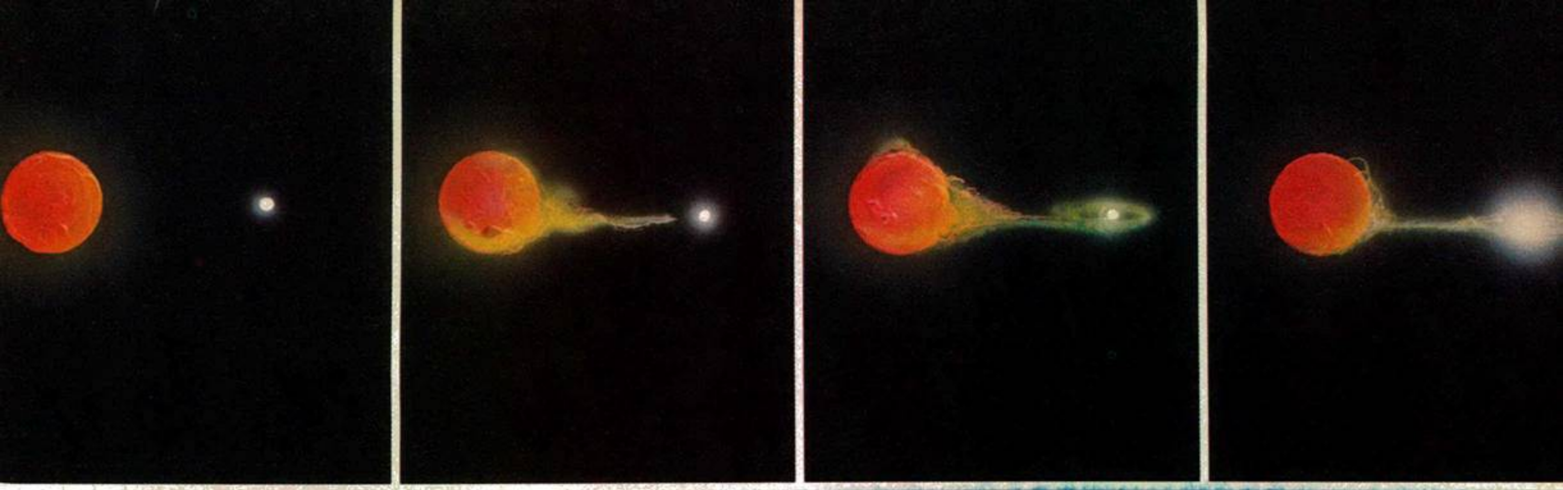
In the early 1960s, Robert P. Kraft (then of the Mount Wilson and Palomar Observatories) examined the spectra and light variations of stars known to have had nova outbursts in the past. Some of the stars were *classical* novae, which have erupted only once in recorded history; some were *recurrent* novae, which have smaller eruptions at intervals of about 50 years, and others were *dwarf* novae, which have still smaller eruptions every month or so.

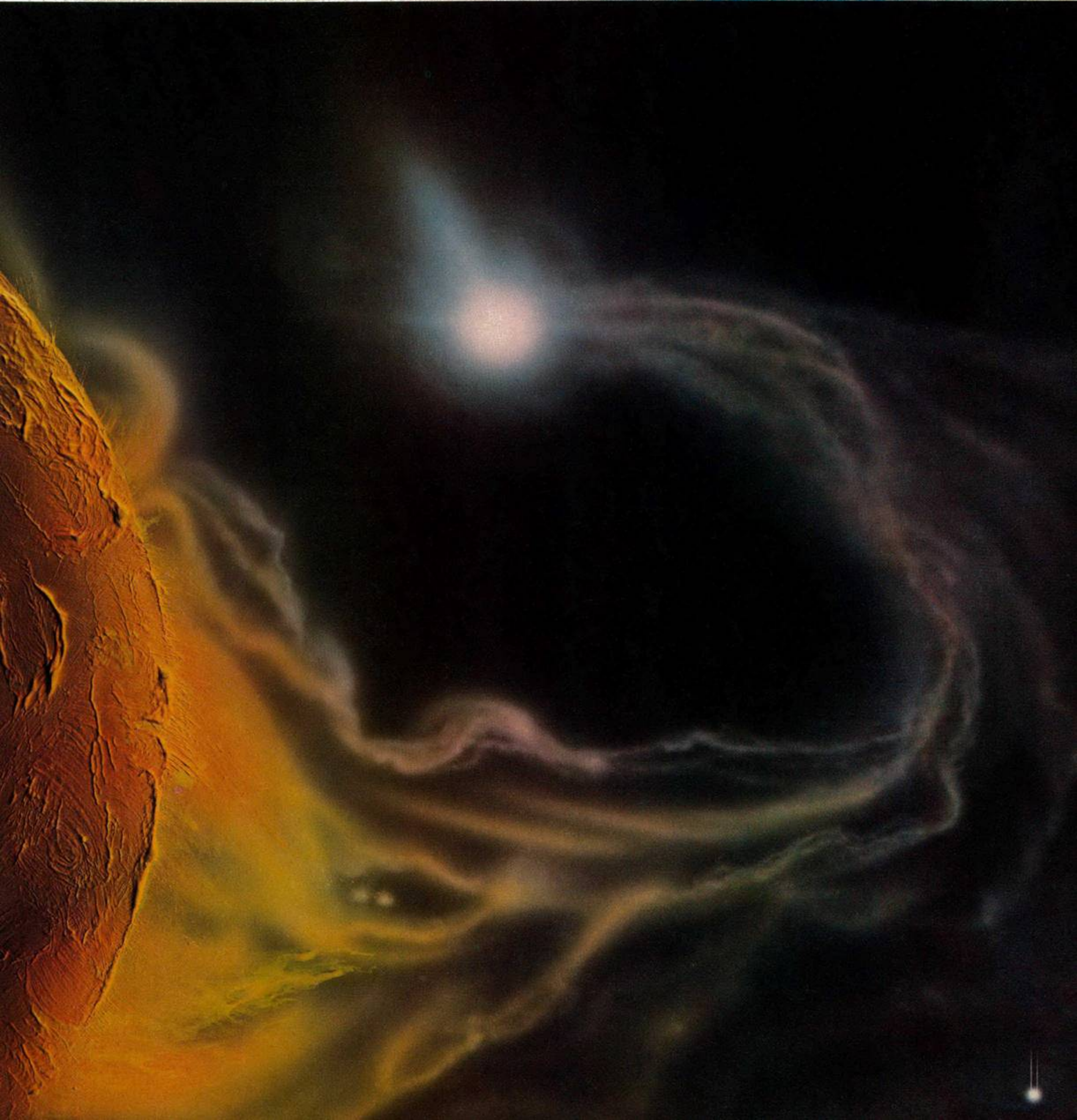
Kraft found that the great majority of these stars were in close binary systems, consisting of two stars orbiting around each other with typical periods of about four hours. One of the two companion stars was usually a normal, red, main sequence star which — like our sun — burns nuclear fuel for its energy. But the other star (the one believed to erupt as a nova) was found to be a white dwarf — a dying star with no nuclear fuel left to burn, which has collapsed down to a fraction of its former size. The evidence was not conclusive, but it appeared likely that all three types of nova always occur in close binary systems like those observed by Kraft.

This discovery led to a flurry of speculation as to how stellar explosions might originate in close binary systems. When the smoke cleared, a single model had "won" — the so-called *thermonuclear runaway model*. Until recently the thermonuclear runaway model was widely accepted.

This model worked in the following way: Hydrogen, the most abundant constituent of all main sequence stars, is ripped from the surface of the normal star by the force of the white dwarf's gravity. The hydrogen eventually finds its way to the white

Top, left to right: The accretion theory of novae begins with a white dwarf orbiting a faint red star. When the red star "burps" a chunk of gas toward the companion, it forms a ring of gas for a short time. The ring expands into a disk and spirals inward toward the white dwarf. The eruption is now in full swing (fourth frame). Below: In the aftermath of the eruption, the accretion disk is faint, although a small stream of gas continues to flow from the red star. Artwork by Mark Paternostro.





dwarf's surface, where it gradually builds up in quantity. If any of this hydrogen diffuses down to the core of the star, an explosion situation develops. To understand why, let's look at the bizarre physics of white dwarfs.

Though containing as much mass as our sun, a white dwarf is a real midget among stars — only a few thousand miles across, or approximately the size of Earth. Its density is so great that one cupful of white dwarf matter would weigh about as much as a herd of 100 elephants! Unlike main sequence stars, which support themselves against the crushing power of their own gravity by maintaining an immense internal temperature and pressure, a white dwarf holds itself up by virtue of its great density.

White dwarf matter is so dense that it does not behave like the gas in an ordinary star. It is more like a rock than a gas. If you try to compress a gas, it pushes back with a force that depends on its temperature; raise the temperature of the gas, and it will push back harder because it is expanding. But what happens when you heat a rock? It does expand by a tiny amount, but compared to the gas that expands so freely when heated, the rock just sits there getting hotter and hotter until it finally melts. The key fact is that the outward pressure exerted by solid matter, like rocks and white dwarf material, depends only on the density of the material and not on its temperature. From this seemingly obscure point can stem the most vexing of problems for the white dwarf.

Remember that the hydrogen on the white dwarf's surface begins to diffuse down to its core. Although the white dwarf doesn't have any hydrogen of its own (having used it up long ago in earlier stages of its evolution), the hydrogen "stolen" from the companion star can ignite in a normal way via nuclear reactions once it reaches the high core temperatures. Because the white dwarf's outward pressure does not depend on temperature, while the rate of nuclear reactions does, the star can get into a real "jam".

Consider that when hydrogen starts to burn, energy is released and the star's temperature rises. Any normal star would expand slightly due to the added pressure this higher temperature creates. This expansion would lower the temperature, which would in turn lower the rate of nuclear burning to a point where the star could remain stable, quietly burning its hydrogen.

This is not the case for the white dwarf. Although nuclear reactions are heating the white dwarf, it does not expand since it is not being supported by heat pressure to begin with. In the same way that heat builds up inside a tightly sealed pressure cooker, the temperature of a star held rigid by its enormous density begins to climb. As it does, the nuclear burning rate also goes up. A chain reaction begins whereby additional nuclear burning heats the star even more, causing more burning, which heats the star even more, and so on. Finally, the star explodes. And instead of food on the ceiling (as you get when a pressure cooker explodes), the entire surface of the star is violently expelled into space. This process is called a "runaway", because once it starts, it cannot be halted in any noncatastrophic way.

The thermonuclear runaway model seemed a plausible explanation of nova outbursts and gradually found its way into many astronomy textbooks. Now recent evidence may require the textbooks to be rewritten — as is often necessary with the advance of science.

In the late 1960s and early 1970s, close binary stars came under careful scrutiny. Thanks largely to the pioneering efforts of R. Edward Nather of the University of Texas, new equipment and computer oriented observing techniques were developed that allowed the stars to be more acutely observed than ever before. All such systems were already known to exhibit slight changes in brightness — *flickering* — that take place over periods of minutes or less. By studying the pattern of the stars' flickering, it became clear that the white dwarf is surrounded by a luminous disk of gas, created by matter flowing over from the companion star. This *accretion disk*, from which matter constantly spirals in toward the white dwarf, was often brighter than either of the two stars in the system.

Astronomers now had a new element to work with in picturing what causes the nova phenomenon. As they realized the importance of the accretion disk, an alternative theory was spawned. Proposed in 1973 by Geoffrey T. Bath of Oxford University, the *accretion theory* treats the gravitational potential energy of matter falling into the white dwarf as the power source for novae.

The setting for the new model is almost the same as that for the older thermonuclear runaway model. There are the two companion stars — the white dwarf and the normal star. This time, however, matter pulled from the normal star does not fall directly onto the surface of the white dwarf. Instead, it first becomes part of the accretion disk — a bright, encircling halo of gas spiraling toward the white dwarf like water in a bathtub spiraling down the drain.

As this gas spirals inward, gravitational potential energy is released. How? Gravity can cause the release of energy whenever something falls toward something else. A meteor caught by Earth's gravity, for example, falls downward ever faster because it is gaining energy from Earth's gravitational pull. In the same way, gas in the accretion

Nova Cygni burst on a startled world: Suddenly one night there was a new star in Cygnus that hadn't been there the night before! Of course, it *had* been there, but had been too faint to be seen. The "new" star appeared distinctly red in a small telescope. This shot was taken with a six inch reflector. Photograph by Robert Provin.

disk gains energy as it approaches the white dwarf. This added energy is released in the form of heat. Near the middle of the disk, infalling gas may raise temperatures to as much as one million degrees. In a way again similar to an Earthbound meteor, the heat energy released is accompanied by a bright surge of light. As the gas finally hits the white dwarf's surface, it raises the star's temperature and releases even more light.

According to this model, the star does not explode. Together with its accretion disk, its brightness simply flares up periodically, dying down only when the amount of matter falling inward begins to decline. It is easy to see that the violence of the outburst depends on how large a chunk of gas is "burped" from the normal star to the white dwarf at any given time. Large infrequent burps make recurrent and dwarf novae.

Which, then is the correct model? Are nova outbursts powered by thermonuclear runaways? Or are they powered by matter spiraling downward in an accretion disk? Most astronomers would have voted for the runaway model until 1975, when two important events occurred to establish the accretion theory as the likely explanation for at least two of the three types of nova.

In August 1975, Earth orbiting x-ray telescopes discovered a new x-ray source in the constellation Monoceros, which became for a few days the brightest source of x-rays in the sky. The position of the x-ray nova was photographed at visual wavelengths, revealing — to everyone's surprise — a star shining 600 times brighter than normal! Inspection of old photographs showed this star had previously erupted in 1917, and hence appeared to be a recurrent nova.

The connection of a recurrent nova with an x-ray nova gave the accretion theory an important foothold. An x-ray nova is widely believed to originate from accretion of gas onto a white dwarf or neutron star. Therefore, Nova Monocerotis 1975 is an object powered by accretion. It is also a recurrent nova. The case for the accretion model of recurrent novae had been made.

Several months later, the same case was made for dwarf novae. In November, the dwarf nova RU Pegasi erupted. Careful monitoring by optical telescopes at the McDonald Observatory revealed the star's behavior from early in its eruption. Evidence which would exclude the thermonuclear runaway model stems from the observed changes in the temperature of the white dwarf in RU Pegasi.

Think back for a moment to the older model. Remember that before the outburst began, the white dwarf had to undergo a chain reaction process sparked by hydrogen burning within the body of the star. The star got hotter and hotter before finally exploding to relieve itself of the unbearable pressure created by the soaring temperatures. Since the explosion is a last drastic effort to relieve the added pressure, you'd expect the white dwarf to be hottest just prior to exploding.

In the accretion model, on the other hand, the heating of the white dwarf comes from the terrific impact of infalling matter hitting its surface. The star will continue to be heated as long as the matter continues to fall. You would expect the temperature to climb throughout the eruption, with a drop-off occurring only after the matter has ceased raining down on the white dwarf.

What does the evidence say? Did the temperature of the white dwarf peak early or late in its eruption? The observations of RU Pegasi show that the temperature peaked six days after the eruption began, and two days after the nova was brightest. This result agrees well with the picture of a white dwarf being heated by infalling matter, but is very difficult to reconcile with a thermonuclear runaway. This led scientists to conclude that dwarf novae are not powered by thermonuclear runaways.

What about classical novae — those that occur at *very* long intervals? Since these outbursts seem to originate from binary systems identical to those producing dwarf and recurrent novae, it would be highly desirable to have a single, unified model for all three. Such a model would again invoke accretion as the likely energy source.

But, as attractive as a single unified theory may be, the classical novae may be an entirely different phenomenon. Their eruptions are far more violent and infrequent and — unlike dwarf novae — they expel large amounts of matter and energy into interstellar space. Perhaps a thermonuclear runaway really does occur in these white dwarfs, but only after the amount of accreted hydrogen becomes very large. In that case, a dwarf nova could actually become a classical nova when the critical limit of accreted hydrogen is exceeded. This speculation is attractive since it answers a very thorny question: How do the white dwarfs in the smaller novae get rid of all that accreted hydrogen? They must get rid of it somehow, or the white dwarf will grow in mass until it can no longer support itself — in which case the star will collapse completely and produce a supernova. But if this were to happen, we'd expect to see more supernovae than we do see. Thus the extreme rarity of supernovae suggests that novae have a very effective process for expelling extra mass, perhaps inflicting minor catastrophes on the star in order to save it from total destruction. For these reasons, among others, the thermonuclear runaway model is still a viable explanation of classical novae.

The advances in understanding novae related here are only a small part of the story. Each new nova outburst must be giving us important clues to the eventual fate of these common and very old stars. But only an occasional clue is grasped, while these energetic oldsters continue to make life in the galaxy interesting. ◆

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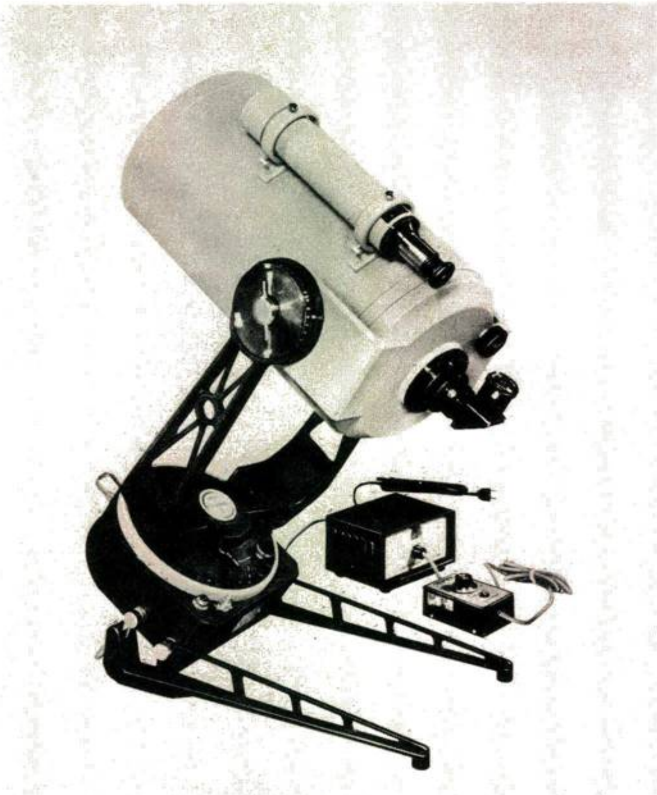

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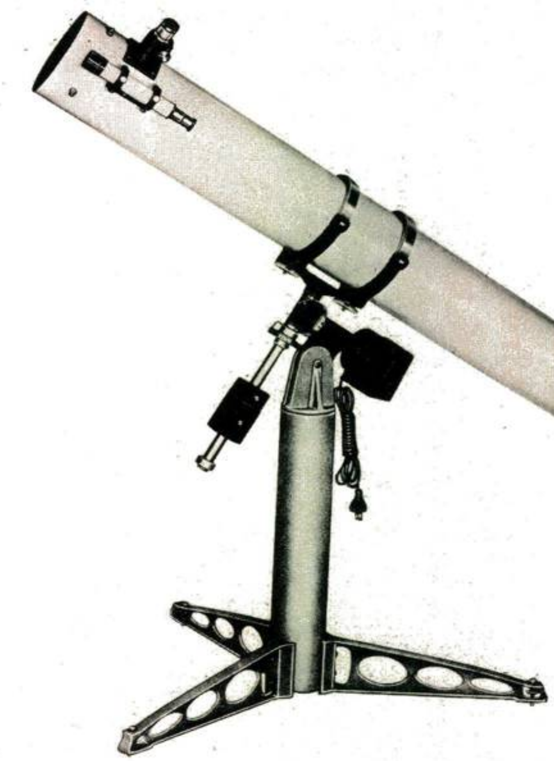

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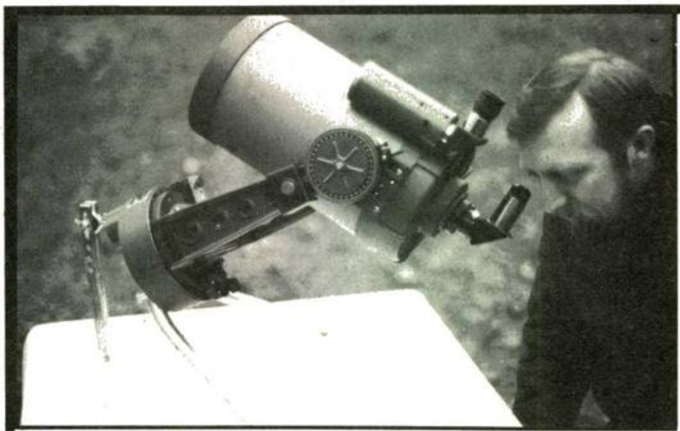

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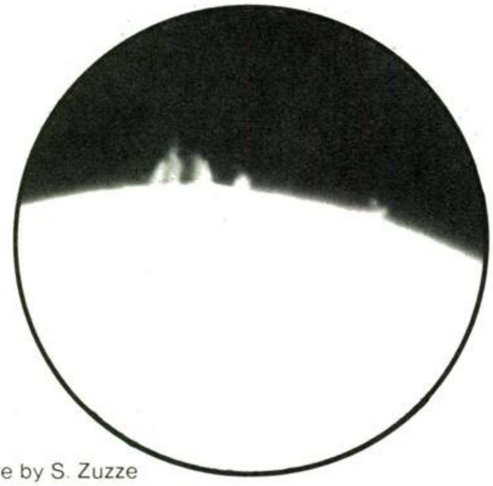

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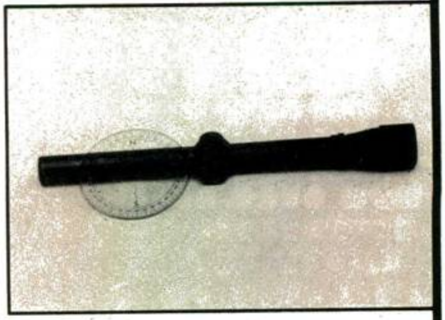

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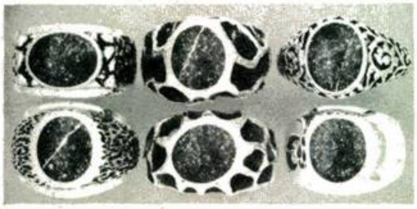

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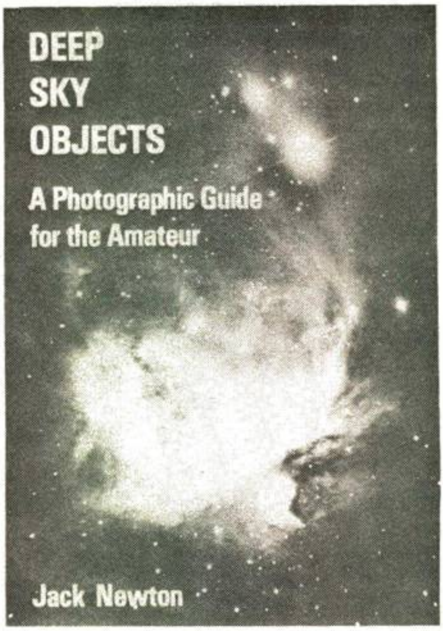

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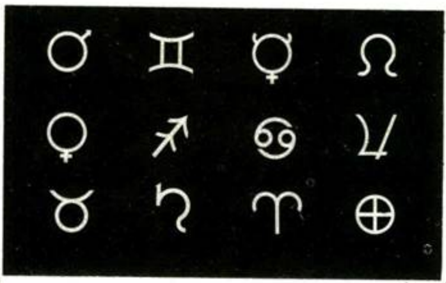

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FOR SALE — Celestron 8, special coatings, wedge, tripod, 2x Barlow, Canon camera adapter, illuminated reticle, right ascension and declination drive corrector, ocular case. Used once; new $1,450.00. Price: $1,150.00. Contact Chuck Ellerbrock, 4254 Harvest, Toledo, OH 43623. Phone (419) 475-1940.

TRADE — 1972 Honda CB-100, 6,900 miles (like new); helmets, shields, tools, other extras (valued at $400.00) for suitable telescope with drive (6" or 8" Cave, or 3.1" Meade). Write Robert Fletcher, 341 Conifer Ct., Walnut Creek, CA 94598.

TRADE — 6" Edmund reflector (clock drive, 50mm right angle finder, 2 eyepieces), and 20x80mm binoculars, tripod for good refractor (preferably RFT, Celestron 5). Meet halfway within 300 mile radius of Indianapolis. Contact Michael Downs, 4280 Genoa Ct., Indianapolis, IN 46236. Phone (317) 899-5779.

WANTED — NASA "SP" books, Apollo 8, 9, 10, 11, 12, 13, 15 preliminary science reports. Will pay double if in excellent condition. Send letter to Robert Wlock, Van Auken Rd., Newark, NY 14513

WANTED — ASTRONOMY back issues in good condition: September through December 1973; January, February, April, May, August, October, December 1974; January through April 1975. Will pay reasonable price. Contact Bill Boryczka, 4067 E. 44th St., Newburgh Hts., OH 44105. Phone (216) 883-3193.

WANTED — Single lady booked on Sitmar's October Eclipse cruise (see p. 71, April issue) seeks lady to share accommodations at "double occupancy" savings. Contact Janice Anderson, 22 Salamanca Ave., #702, Coral Gables, FL 33134. Phone (305) 443-0827 or 324-1133.

WANTED — Correspondence with other amateur astronomers; any age. Write Matt Arnold, 1905 Cooper Circle, Camp Hill, PA 17011.

WANTED — 3" f/15 achromat objective lens (or similar) for replacement in an Edmund refractor. Send details, price to Douglas Braun, 263 N. Pascack Rd., Spring Valley, NY 10977.

WANTED — Used Strasbaugh polishing machines and Loh machines. Please specify pan size, year, price. Contact V. Caracci, 247 N. Linden St., Massapequa, L.I., NY 11758. Phone (212) 798-8459.

WANTED — Members for nationwide philosophy/science group based on Frank Herbert's "Dune" and "Star Trek". Wish to make "Dune" society a reality via "Star Trek" technology and space exploration. Write A. Dan Curtis, 8212 Candleglow Ln., Louisville, KY 40214.

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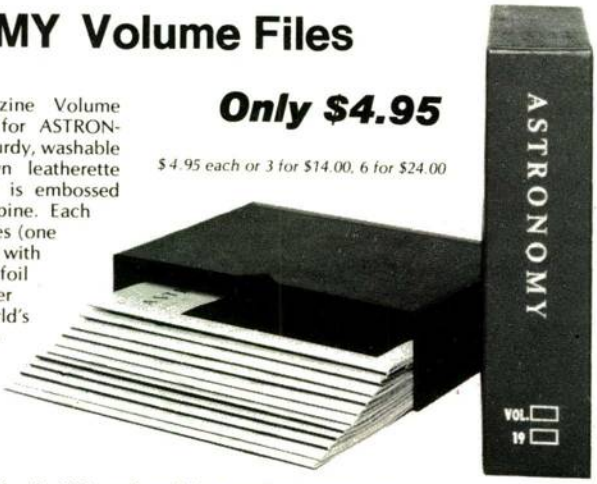

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WANTED — Correspondence with persons (preferably female, ages 12 to 14) interested in astronomy, space, interstellar travel, extraterrestrial life and communication, science fiction, time travel. Write Steven Geary, Rt. #1, Rolling Prairie, IN 46371.

WANTED — Members for National Deep Sky Observers Society. For more information, write Alan Goldstein, National Coordinator, 3430 Bryan Way, Louisville, KY 40220, or Tom Bryant, Western Coordinator, 2000 Walnut St., #32, Boulder, CO 80302.

WANTED — Contact with individuals, special interest groups with information on UFO sightings, other UFO related phenomena in Colorado. Information to be included in book in progress. Contact Michael James, 3355 S. Ogden, Englewood, CO 80110. Phone (303) 789-0361.

WANTED — Astronomy reference handbook. Will pay up to $10.00. Write with details (enclose SASE) to Robert Jones III, 70 Mayfair, Tuscaloosa, AL 35401.

WANTED — Correspondence with persons interested in science fiction or "Star Trek" (especially Spock fans). Write Phyllis King, 225 E. Allen Ave., Monticello, AR 71655.

WANTED — Correspondence exchanging ideas with individual interested in astronomy, astrophysics, science fiction, extraterrestrial life, interstellar travel, and/or those owning Celestron 8. Write Peter Kuhl, 188 Beechwood Ave., Bogota, NJ 07603.

WANTED — If you teach astronomy, I'd like to swap copies of successful indoor or outdoor classroom activities. Write Bill Byles, Astronomy Instructor, Briarcrest Baptist High School, 842 Sweetbriar, Memphis, TN 38138.

WANTED — Anything pertaining to "Star Trek". Write Robert DeVivo, 187 E. Clinton Ave., Bergenfield, NJ 07621.

WANTED — Complete set of ASTRONOMY: Vol. 1, No. 1 (August 1973) through Vol. 4, No. 8 (August 1976). Must be in excellent condition. Send price to Linda M. Kurylo, 675 N. Elm St., Wallingford, CT 06492.

WANTED — Information on amateur astronomy organizations; am eager to join. Also correspondence with teens on astronomy, science fiction, interstellar travel, etc. Write Jeff Linstrom, 1526 Saunders Dr., Wooster, OH 44691.

WANTED — Astronomical art, large map of moon, model of Viking. Send condition and price information to Yvonne McMickens, 254 Race St., Berea, OH 44017.

WANTED — Good quality B&W or color slides (2" x 2") of star fields, including parts of or whole constellations. Will pay $1.00 per slide after verification. Write John Marshall, 1 Gracie Terrace, Apt. 7D, New York, NY 10028.

WANTED — 70 to 90 H.P. McCullough drone engine for Bensen Gyrocopter. Contact Andrew Palkovich, 428 Merrill Ave., Fond du Lac, WI 54935. Phone (414) 922-1938.

WANTED — Inexpensive clock drive in good condition to fit 1" shaft and 1-1/2" housing. Also 1-1/4" camera adapter for Canon SLR. Contact Jay Russo, 918 E. Fairchild, Iowa City, IA 52240. Phone (319) 338-0128.

WANTED — Deep sky photos (for research project) to faintest magnitude possible, covering following areas: R.A. 13h, 32m 33s, Dec. 10° 15m; or R.A. 12h 48m 14s, Dec. 5° 48m. Write Harald Schenk, 2330 S. 11th St., Sheboygan, WI 53081.

WANTED — Serious individuals to assist California branch of national ufological organization in statewide network of investigators, consultants, lecturers. Must be of age, reliable; supply own transportation. Write Space Science Media Group, UFO Project, c/o John Sigwing, 652 Glenmore, Glendale, CA 91206.

WANTED — Correspondence with owner of Continental Optics 3" refractor. Also information on joining a Tolkien fan club. Write Scott Telles, 130 Clooney Dr., Henrietta, NY 14467.

WANTED — Maksutov; Newtonian-Cassegrain blanks, mirrors, accessories, mounts. Will accept unfinished telescope projects over 5". Write D.C. Werbeck, 5235 S. University, Chicago, IL 60615.

WANTED — Members for national philosophy/science group based on Herbert's "Dune" and "Star Trek". Wish to make "Dune" society reality via "Star Trek" technology, space exploration. Write Lance E. Groth, c/o Project Endeavor, 320 6th St. S.E., Pipestone, MN 56164.

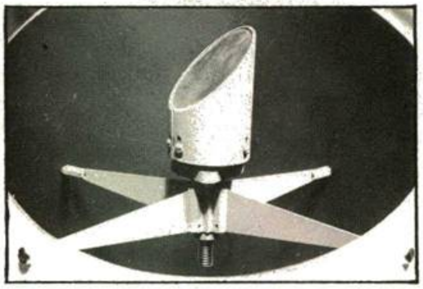
INFORMATION WANTED — On Dr. Gerald O'Neill's work or others (O'Leary, NASA, etc.) on space colonization. Also information on all areas of NASA work. Will reciprocate, if desired. Write Robert L. Coppedge, P.O. Box 993, Hiram, OH 44234.

INFORMATION WANTED — On any astronomy club in Concord, N.H. area. Also on theoretical hyperspace travel, nuclear propulsion systems, three dimensional star maps, current address of Carl Sagan. Write Eliot Clemons III, 1 Tallyho Ln., Bow, NH 03301.

INFORMATION WANTED — On UFO, "Star Trek" or science fiction clubs in Mesa area which would accept a highly interested 14 year old. Write David R. Negrette, 2540 W. Laguna Azul Ave., Mesa, AZ 85202.

INFORMATION WANTED — On whereabouts of any northern New Jersey astronomy clubs or organizations. Would like to become a member. Contact William J. Kane, 805 11th Ave., Paterson, NJ 07514. Phone (201) 278-8818.

SECONDARY HOLDERS AND SPIDERS



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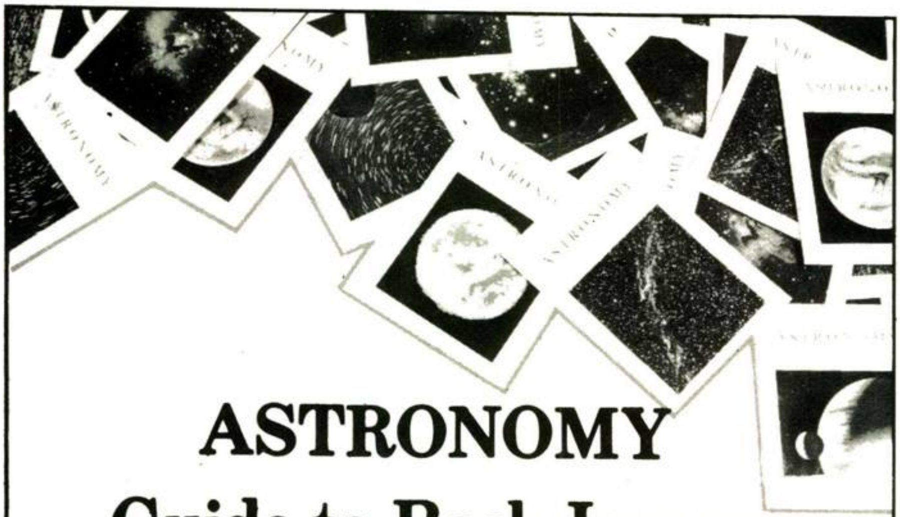

ASTRONOMY
Guide to Back Issues

Reader interest in back issues of ASTRONOMY magazine is higher than ever. As a result, our stock of back issues is swiftly dwindling. Below is a guide to ASTRONOMY back issues that are still available. For your convenience it is updated monthly; issues not listed are depleted.

When ordering, please clearly state quantity, volume, number, month and year for each issue (first issue was August 1973), and include payment with your request. If issues ordered are no longer available, unless you instruct us to forward a refund or substitute issues, we will automatically extend your subscription appropriately.

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INFORMATION WANTED — Ideas, helpful hints on starting astronomy club. Also correspondence with persons interested in starting astronomy club in the Larned, Kansas area. Write Tom McKinney at General Delivery, Lewis, KS 67552, or 310 W. 4th, Larned, KS 67550.

INFORMATION WANTED — Would like to know your 10 science fiction favorites in each of the following categories: 1) best TV show; 2) favorite character; 3) best "Star Trek" show. Write Perry G. Moore, 1326 Burton Valley, Nashville, TN 37215.

INFORMATION WANTED — Addresses of individuals or firms selling meteorite specimens. Write Joe Panzarino, 2310 Sabal Palm Dr., Miramar, FL 33023.

FREE — "Tonight's Asteroids", bimonthly newsletter featuring high quality tracking charts for currently observable asteroids, comets. No obligation. Send 4 long SASEs for next 4 issues to J.U. Gunter, 1411 N. Mangum St., Durham, NC 27701.

FREE — Facts regarding masses with C-plus relative velocities (tachyon scandal "exposed"); fundamentals; light propagation; corpuscular optics; field theory. Write William T. Thomas Jr., 408 Vermont Ave., Daytona Beach, FL 32018.

ANNOUNCEMENT — Classes in mirror making, telescope assembly, theory, use, design being held by Amateur Astronomers Association. Write A.A.A., Optical Division, c/o Hayden Planetarium, 81st St. & Central Park West, New York, NY 10024.

ANNOUNCEMENT — If you have a question about "Star Trek", we can get the answer for you. Please enclose SASE when requesting information. Write Star Trek Welcommittee, c/o Mary Dodge, P.O. Box 207, 93 Vosper St., Saranac, MI 48881.

ANNOUNCEMENT — "Deep Sky Monthly", newletter on best deep sky objects is available. You pay for postage only ($2.50 per year). For further information, write David J. Eicher, 104 Oakhill Dr., Oxford, OH 45056.

ANNOUNCEMENT — Tentative arrangements being made for National Deep Sky Observers Society convention, July 15-17 in Louisville. Contests, observing sessions, papers, etc.; nonmembers invited. Write Alan Goldstein, NDSOS Convention, 3430 Bryan Way, Louisville, KY 40220.

ANNOUNCEMENT — Northwest Region, Astronomical League Convention will be held July 16 & 17 at Science Building, University of Puget Sound, Tacoma. Public invited to attend. For details write Steve Mackey, Co-Chairman NWRAL, 2211 N. Whitman, Tacoma, WA 98406.

ANNOUNCEMENT — Join the Johnson Space Center Astronomical Society for solar eclipse expedition from Houston/Miami to Colombia (Oct. 9-15). Contact ECLIPSE, c/o Paul D. Maley, 3615 Ledgestone Dr., Houston, TX 77059. Phone (713) 488-6871.

ANNOUNCEMENT — National Amateur Astronomers' Convention will be held Aug. 10-13, 1977 at University of Colorado in Boulder, with participation of AL, ALPO, IOTA, WAA. For information, write Denise Nye, NAA Convention Registration, 5604 Bowron Pl., Longmont, CO 80501.

ANNOUNCEMENT — Amateur astronomy night course at Pierce College starts July 11. Topics include: purchasing a telescope, use of telescope, observing skills, basic astronomy, constellation identification, astrophotography. For details, contact Community Services, Pierce College, Woodland Hills, CA 91364. Phone (213) 884-4455.

ANNOUNCEMENT — $100 reward to anyone who can come up with previously unreported meteorite. For further information, send long SASE to Paul P. Sipiera, Field Museum of Natural History, Chicago, IL 60605.

ASTRO-NEWS

Latest News From the World of Astronomy

Satellite Tracks Sailboat

The value of satellites in search and rescue missions for small craft at sea was recently demonstrated by a retired NASA engineer and a Florida family of three who sailed a 33 foot (10 meter) sailboat 600 miles (965 kilometers) through the "Bermuda Triangle" area.

During the 30 day trip, a satellite relayed the general location and condition of the voyagers to engineers at NASA's Goddard Space Flight Center in Greenbelt, Md.

Small or medium sized craft venturing into the open sea usually must rely on marine radio telephone communications. Such systems are limited to about 25 miles (40km) line-of-sight range. Other longer range voice radio equipment is subject to static and is often unreliable.

The principle experimenter for the satellite search and rescue test was James L. Baker, a retired NASA engineer from Sherwood Forest, Md. He conducted the extensive tests aboard the sloop "Sirius". Owner Louis Van Houten of Key Biscayne skippered the craft with his wife and son as crew.

NASA's Nimbus 6 meteorological research satellite kept tabs on the four voyagers by monitoring continuous signals from a small transmitter on the sailboat. This battery powered unit, normally carried by meteorological balloons, automatically sends out a signal once a minute for relay to Goddard via the satellite.

Within an hour after the data was received at Goddard, a computerized system printed out information on the sailboat's position. About 40 percent of the positions, as derived from the satellite data, were within one mile (1.8km) of the true positions. The overall accuracy of the derived positions was within three miles (4.8km).

From its polar orbit, Nimbus 6 was able to track the sailboat for about 3-1/2 hours around local noon, and another similar period of time around local midnight each day.

As part of the test, Baker evaluated a pushbutton distress alarm system which was connected to the onboard transmitter. Simulated distress messages, craft identification, and weather and cruising conditions were relayed successfully via the satellite to Goddard with this device.

The pushbutton unit, developed by Baker under contract to Goddard, is designed to repeat its distress message automatically, once energized. Thus, a crew confronted with a genuine emergency could initiate the distress message and then turn its attention to meeting the emergency.

Because of the compactness and light weight of the transmitter, its battery and antenna, and the pushbutton unit, the entire system could be transferred quickly to a lifeboat if necessary.

Baker coordinated the experiment with Goddard through a NASA communications research satellite, the Applications Technology Satellite 1 (ATS-1).

Still in use after more than 10 years in orbit, the ATS-1 is positioned in a stationary orbit some 22,300 miles (35,680km) above the equator, just south of Hawaii. From there, the satellite commands a view extending from Japan to the Atlantic waters off our east coast.

While south of Nassau, Baker established contact with Japan's Kashima ground station through the ATS-1. This test of the system proved the longest communications distance ever covered from a sailboat using a single satellite for relay.

"It was a comfortable feeling for us to know that Goddard had up-to-date information on our position and cruising conditions, particularly since we were in the notorious Bermuda Triangle where many craft have disappeared," Baker said after the voyage.

Two Galaxies Discovered

Two interesting dwarf galaxies have been discovered by astronomers studying the southern sky with new telescopes recently "opened" in Chile. The first galaxy is on the edge of our local group, while the second is possibly the faintest galaxy of its type ever seen.

Both galaxies were first noted by astronomer Richard West (discoverer of comet West) on plates taken with the one millimeter Schmidt camera at the European Southern Observatory at Cerro La Silla. The first object, in the constellation Phoenix, has now been studied in detail by R. Canterna and Phillip J. Flower of the University of Washington, using the four millimeter reflector at Cerro Tololo Inter-American Observatory.

They found that the Phoenix object is an irregular dwarf galaxy similar to — but three times farther than — IC-1613 in our local group of galaxies. Canterna and Flower estimate that the new galaxy is about six million light-years away. This is too distant to be part of our local group, which has a diameter of about three million light-years. Nevertheless, the Phoenix dwarf galaxy is still one of our closest galactic neighbors.

The second new galaxy, in the constellation Sculptor, has been studied by West and his colleagues with the European Southern Observatory's 3.6 millimeter reflector. This dwarf irregular galaxy is similar to IC-1613 and the Phoenix object. The European astronomers say this galaxy lies in the Sculptor group of galaxies, about 9-1/2 million light-years away. It appears to be intrinsically the faintest irregular galaxy known — nearly 10,000 times fainter than our own galaxy.

HEAO Experiments Detailed

There's a gust of fresh air blowing through the realm of astronomy, and it just may shake the very foundations of physics.

Specifically, that fresh air is coming from the area of high energy physics for which the High Energy Astronomy Observatories (HEAO) were named. The observatories will study objects that radiate in the x-ray, cosmic ray and gamma ray wavelengths. These wavelengths are shorter than those of television or radio and are much higher in the level of energy — therefore, the name high energy astronomy.

The mission consists of three observatories: HEAOs A, B, and C, designed to orbit above Earth's atmosphere as they study a wide variety of celestial objects such as pulsars and neutron stars, black holes, quasars, radio galaxies and supernovae.

HEAO-A

HEAO-A is to perform an all-sky survey of x-ray and gamma ray sources and background, and to obtain data in a pointed mode on selected targets of interest.

The *large area x-ray experiment* (A-1) consists of seven modules, six on one side of the observatory and one on the other. The modules contain x-ray detectors called proportional counters. The large area of counters on A-1 allows for relatively weak sources to be studied. The electronics were designed to measure the very rapid fluctuations which have been found to occur in some x-ray sources. This latter ability is thought to be one of the keys to determining the existence of a "black hole".

The objective of the *cosmic x-ray background experiment* (A-2) is to study the details of the diffuse x-ray background which so far has not been resolved into discrete sources. An accurate measurement of this background is vital to a complete understanding of the cosmological processes of high energy astrophysics.

As with A-1 and A-2, x-ray detection on the *scanning modulation collimator* (A-3) is based on the gas filled proportional counters. A-3 has a major design difference, however, in the use of arrays of fine wires in front of the counters. These will generate "shadows" in the x-ray flux as the rotating observatory moves the instrument across the sky. To achieve the high location accuracy, alignment between A-3 and the star trackers must be held to extremely tight tolerances. This is why they are mounted directly to the A-3 frame instead of in the equipment module some distance away.

Unlike the other three HEAO-A experiments, the *hard x-ray and low energy gamma ray experiment* (A-4) uses no gas filled counters. Because of the higher range of energy studied, a solid substance is needed to absorb and measure the x-rays and gamma rays. A particularly important feature of A-4 is its special circuitry for detecting and measuring the properties of the mysterious gamma ray bursts.

HEAO-B

The primary objective of the HEAO-B mission is to study individual x-ray objects in detail using an advanced x-ray telescope. Because the telescope concentrates the x-ray flux, objects much fainter than those so far observed can be examined in detail. Also, unlike HEAO-A instruments, the telescope can form images of x-rays of extended objects such as supernova remnants.

The HEAO-B observatory will spend most of its one year life in a pointed mode, maneuvering from one target to the next as instruments are moved in and out of the focal plane.

There are two experiments on HEAO-B which are designed to take advantage of the imaging capability of the x-ray telescope, the largest in the world. One is the *high resolution imager* (B-1), which used advanced solid state techniques to record the images to the limit of the resolution capability of the telescope itself. The other imaging instrument is called an *imaging proportional counter* (B-2). It uses the same basic technique as most of the x-ray detectors on HEAO-A, but the counter is electronically subdivided into very small regions so that each registers a small part of the x-ray image. What the imaging proportional counter lacks in imaging resolution, it makes up in greater field of view than the high resolution imager.

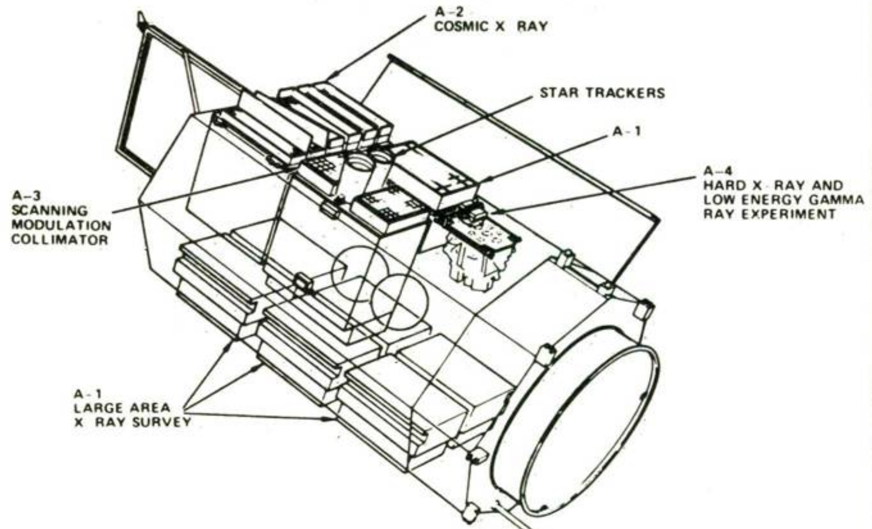
Another instrument is the *focal plane crystal spectrometer* (B-3), which makes use of x-ray diffraction properties of certain crystals to study in detail the x-ray spectra produced by the celestial targets. The detector for the diffracted rays is a small proportional counter. This instrument can detect individual x-ray emission lines to help unravel questions about the chemical composition and other properties of the x-ray targets.

The other spectrometer on HEAO-B is the *solid state spectrometer* (B-4). Its advantage is that it can observe the entire spectrum at once, measuring the energy (and therefore wavelength) of each photon which strikes the crystal.

One additional instrument, mounted near the front end of the observatory, operates independently of the telescope. Called the *monitor proportional counter* (B-5), it observes the same region of the sky as the telescope but over a much wider energy range. It provides a means of correlating observations

HEAO *continued on page 66*

HEAO-A EXPERIMENTS



BRIEFS

● A gigantic iceberg nearly the size of Rhode Island is being tracked by satellite during its 1,800 mile (2,900km) journey along the Antarctic coast toward the open sea, east of South America. Satellite information is helpful in routing icebreakers and United States and foreign shipping vessels through dangerous polar ice fields.

● Using space age technology and techniques, NASA and the National Fire Prevention and Control Administration have begun a program called Project FIRES (Firefighters Integrated Response Equipment System). The program is aimed at improving firefighters' protection against such hazards as heat, flame, smoke, toxic fumes and electrical shock, while at the same time permitting improved performance by allowing greater maneuverability.

● According to the North American Air Defense Command, there were 1,117 manmade objects in space at the end of 1976. This figure was up from the 1975 total of 929 satellites and pieces of debris.

● Researchers at the Francis Bitter National Magnet Laboratory are using a technique called high gradient magnetic separation to "substantially" remove all the inorganic sulfur and 40 percent of the ash-forming materials from samples of liquified coal. Removing the impurities with this process, still in the testing stage, may greatly increase the usable amount of coal for power.

● The most intense steady magnetic field ever achieved has been produced by scientists at the Francis Bitter National Magnet Laboratory in Cambridge, Mass. The scientists used a special hybrid magnet, which they designed and built, that consumes only a fraction of the power of conventional units.

● The highest power transmitter ever flown on a communications satellite (10 times more powerful than previous satellites) has been operating trouble-free for over a year. The Communications Technology Satellite is a joint United States/Canadian venture that provides a wide range of powerful television and emergency communications services to many remote Canadian locations.

Universe Might Be 20 Billion Years Old

For many years it was believed that the universe was anywhere from 10 to 15 billion years old. Now, however, scientists at the University of Chicago have determined that the universe may be much older than originally estimated. In fact, they think it may be as much as 20 billion years old!

Scientists David Schramm and Kem Hainebach of the Enrico Fermi Institute say that according to these new findings, it is believed that the Milky Way galaxy of stars began forming at least 10 billion years ago — and possibly as much as 20 billion years ago. This followed the earlier explosive birth of the universe.

The scientists based their estimates on calculations of how much radioactive rhenium 187 has decayed since that element was first formed in the early history of the galaxy. This form (isotope) of that rare metal has an extremely long halflife of 40 billion years. (This halflife is the half of a given amount that decays in that time.)

It is believed that rhenium 187 began to form from lighter elements during stellar explosions that were taking place early in the history of the galaxy. These explosions, known as supernovae, are thought to generate a number of the heavier elements.

Laboratory tests conducted by the Lawrence Livermore Laboratory of the University of California estimated how much rhenium 187 was originally formed, relative to other isotopes of rhenium — especially rhenium 185, which does not decay.

Assuming relatively steady production of the isotope in following epochs, the proportion of rhenium 187 remaining today could then be used as a means of calculating how much time has gone by since rhenium synthesis began.

"The use of the extremely long-lived rhenium 187 for doing this calculation," Schramm said, "is far superior to the shorter-lived thorium and uranium because some of the rhenium that was produced in the very first processes when the galaxy just formed is still around, whereas the bulk of uranium 238 produced when the galaxy first started producing heavy elements has now all decayed away."

Uncertainties in the calculation of the age of the universe exist principally because of differing ideas of how and at what rate the elements were created.

Schramm and Hainebach said they have done calculations using all recent models for the production of elements in the galaxy.

'With all the uncertainties thrown in," Schramm said, "the age of the galaxy is implied to be some place between 10 and 20 billion years."

This range is in close agreement with the ranges obtained by other methods of estimating the age of the universe, such as the expansion of the universe and the age of the oldest stars. The age obtained by using the rate of the expansion of the universe is between 7 and 20 billion years; the age from the oldest stars gives an age between 9 and 18 billion years.

US Tracking Costs Clarified

Because of recent comment, Australian Science Minister James J. Webster has corrected misstatements of the costs to Australia in support of United States tracking stations.

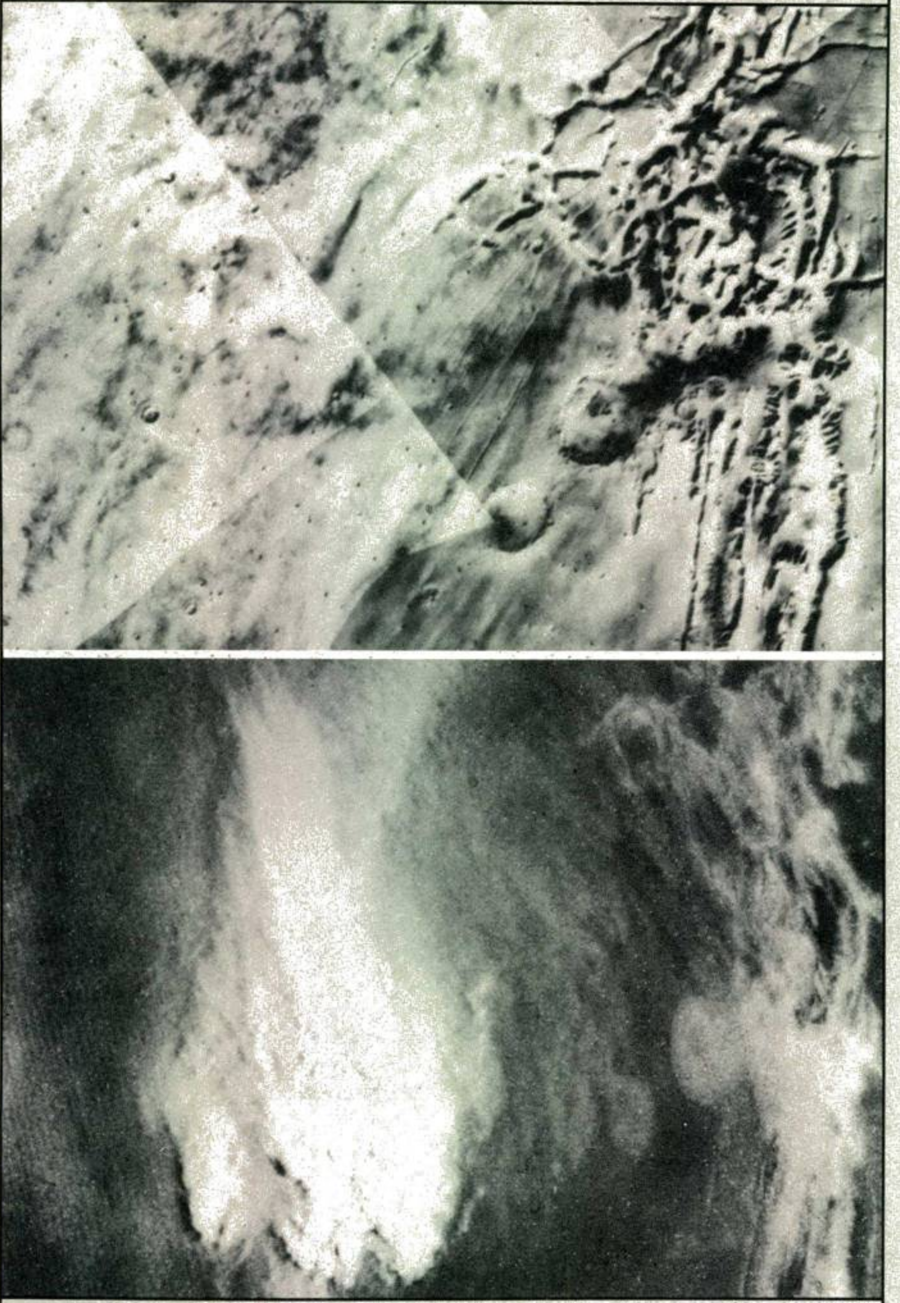
According to Webster, the Department of Science manages three stations for NASA under conditions prescribed in an agreement between the U.S. and Australia. The agreement provides that NASA will bear all the costs of establishment and operation of the stations, subject to any contribution by the Australian Department of Science.

Operation and maintenance services at the stations are currently provided under contract by the Fairey Australasia Pty. Ltd. A new five year contract, to commence Sept. 1, 1977, has recently been awarded to this company. The total value of the new contract is $44,300,000.

The cost of NASA's space tracking activities in Australia is currently about $12 million a year. The Australian Department of Science has contributed about $155,000 annually toward this cost.

"This is a fine example of an international agreement working in the interests of both participant nations," said Webster. "The Australian stations are a vital part of the NASA network, and we in turn share the benefit resulting from the wealth of knowledge gained through space research."

Martian Duststorm: Before and After



These Viking photographs illustrate a duststorm on Mars. In this pair of "before and after" pictures, the western portion of the Valles Marineris canyon system — including Noctic Labyrinthis (upper left in both views) — is just to the north of Solis Planum. The picture on the top is a mosaic of several frames taken by Viking Orbiter 1 on July 31, 1976; the picture at bottom is a single frame taken at an oblique angle by Viking Orbiter 2 on March 25, 1977. The picture on top shows the surface partly covered by diffuse clouds. Solis Planum is a high region on Mars, rising about six miles (10km) above the surface. The cloudiness is probably due to cooling air as it is carried upward by strong upslope winds, forming water ice clouds. In the lower photograph, Solis Planum is covered by a duststorm stretching about 373 miles (600km) long, in the direction of cloud movement (eastward, from left to right). Both structure and appearance of the cloud mark it as a duststorm: The leading edge is sharp, while the trailing portion is diffuse. Cellular structure in the cloud indicates strong turbulence and upward motion. Some water ice is probably mixed with dust, since the picture was taken with a violet filter, and the cloud is still the brightest feature. The general obscuration is due to a large duststorm that started in the same general area about 40 days earlier. The Martian late southern spring and early summer is the dustorm season, due partly to Mars' closest approach to the sun. Mars made its closest approach to the sun in mid-May of this year — historically the point at which the global Martian duststorm has been seen from Earth. NASA photograph.

HEAO

continued from page 64

made by all the focal plane instruments.

HEAO-C

The third HEAO mission provides for gamma ray and cosmic ray instrumentation. Although HEAO-A contains one gamma ray instrument, HEAO-C is the only HEAO observatory offering capability for research on the cosmic rays.

The gamma ray instrument on HEAO-C is called the *high spectral resolution gamma ray spectrometer* (C-1). Like the solid state spectrometer on HEAO-B, this instrument can perform spectroscopic measurements on photons of extremely high energy, whereas the spectrometer covers the entire spectrum. The ability to identify specific line emission from the gamma ray flux may help answer some of the most basic questions about the origin of the universe.

The other cosmic ray experiment, the *isotopic composition experiment* (C-2), is being built in France by the Commisariat à l'Energie Atomique. This French instrument examines a narrower range of energy and nuclear charge than the heavy nuclei experiment, but performs a highly accurate measurement of the nuclear charge. It can identify not only the chemical element responsible for the cosmic ray, but the exact isotope of the element. This more precise knowledge is required to test the validity of some of the theoretical models which have been devised to explain the mechanisms of generation and propagation of cosmic rays throughout the universe.

One of the cosmic ray instruments is called the *heavy nuclei experiment* (C-3). This experiment is the largest in area of any of the HEAO missions, with 50 square feet of cosmic ray collecting area. It records the passage of cosmic rays. The experiment components measure the energy, the direction of travel and the nuclear charge. This latter measurement provides a direct identification of the chemical element represented by the cosmic ray.

The special feature of this experiment is its ability to detect and identify chemical elements with atomic numbers well beyond those presently known on Earth and which, although predicted to exist in space by some researchers, have not yet been conclusively observed.

HEAO-A was launched in late June. HEAOs B and C will be launched in 1978 and 1979. Control of the in-orbit observatories will be under the direction of Marshall Space Flight Center in conjunction with TRW flight control engineers at Goddard Space Flight Center.

Soviets Propose Theory for Physical Behavior of Quasars

Soviet Scientists Vitaly Ginzburg and Leonid Ozernoi have proposed an explanation for the physical nature of quasars. They reasoned that the huge amounts of energy from a quasar come from a gigantic galaxy that has a strong magnetic field.

This hypothesis is by no means the first one that attempts to explain why quasars exhibit the characteristics that they do. Quasars are the most baffling riddle of the universe. Astronomers discovered them in 1963 and were amazed by a large number of their incompatible properties. More than 10 years have passed since then, but theoreticians still cannot build a plausible model of the phenomenon.

What is the explanation for the fact that quasars, while being the most remote objects in the universe, are at the same time the most powerful sources of electromagnetic emission? Why do these cosmic specks (as compared with galaxies) emit more energy than clusters of billions of stars? What fantastic mechanism of energy generation has been invented by nature? Researchers fully concur on one point: Nuclear reactions are absolutely insufficient for the observed effects.

The first hypothesis which gained wide acceptance among scientists was advanced by Soviet astrophysicist Nikolai Kardashov, who said it is possible that an intensive star building process is underway in the galactic nuclei, giving rise to dense clusters in which the stars collide almost daily (by terrestrial clocks). These tremendous explosions incessantly produce so-called supernovae and pulsars (neutron stars), and it is from these compact areas that endless waves of energy spread out into the intergalactic expanses.

The idea was attractive, but when Ginzburg and Ozernoi analyzed it, they found that this model could not explain all the effects produced by quasars. The main thing was that even these powerful stellar catastrophes were inadequate to provide the amount of energy actually yielded by the quasars.

From Albert Einstein's general theory of relativity, it inevitably follows, as Robert Oppenheimer showed in 1939, that all starlike bodies whose mass is at least two or three times larger than the sun's would, upon the burning up of nuclear fuel inside them, begin to shrink under the action of gravitation, and nothing can stop that process. *Black holes* — areas with incredibly strong fields of gravitation which absorb all particles and emission quanta from the surrounding spce — are the result. Estimates allow such a picture. If this cosmic monster has a mass on the order of millions of suns and is located within a star association, its all-devouring gravitation would attract the gas emitted by the stars in the process of their evolution. But accelerated to subluminary velocities, the matter, as mathematical equations show, will not perish in the "gravitational grave", but on approaches to the black hole would transform itself into a powerful stream of electromagnetic emission.

Everything seems all right, even for the energy level this model fits. But Soviet theoretical physicist Igor Novikov has shown that the maximum energy radiation from the black hole quasar would be in the optical and ultraviolet bands. Real quasars, however, concentrate the bulk of their emission in the infrared part of the spectrum. Also, this model doesn't offer adequate explanations for some other effects. In short, the problem of incompatibility cropped up again.

Ginzburg and Ozernoi reasoned that billions of stars within a galaxy, as they evolve, emit a gas which under the effect of gravitation tends to collect at the galactic center, moving in from all directions. After a period of approximately 100 million years, this building material must form a gigantic body with a mass equivalent to one billion solar masses. Such a superstar the size of a solar system rotates and has a strong magnetic field. (Without these two properties, computations show that this mammoth can survive in the emission mode of a quasar for only 10 years.) That is why this unusual body was named a *magnetoid* or a *rotator.*

How did nature construct this rotator capable of flooding the universe with energy for so long? The axis of the magnetic field of this rotator-magnetoid does not coincide with its rotation axis (they form a certain angle). Due to rotational instability, the plasma flows from the equator. Getting into the field of the superstar's magnetic-dipole emission, it is accelerated to subluminary velocities and, slowing down in the magnetic field, begins to emit electromagnetic waves of fantastic power.

This period of the quasar's busy activity lasts about a million years. Then, owing to a series of physical processes — according to the Ginzburg-Ozernoi model — the quasar's energy resources run down, and it is extinguished. The centrifugal forces of rotation flatten its body into a disk, with the physical conditions in it triggering off a cyclopean thermonuclear explosion. The matter of the quasar is scattered all over the galaxy. Then comes another 100 million year period of quasar building, and the entire process repeats itself. *Courtesy of Novosti Press Agency.*

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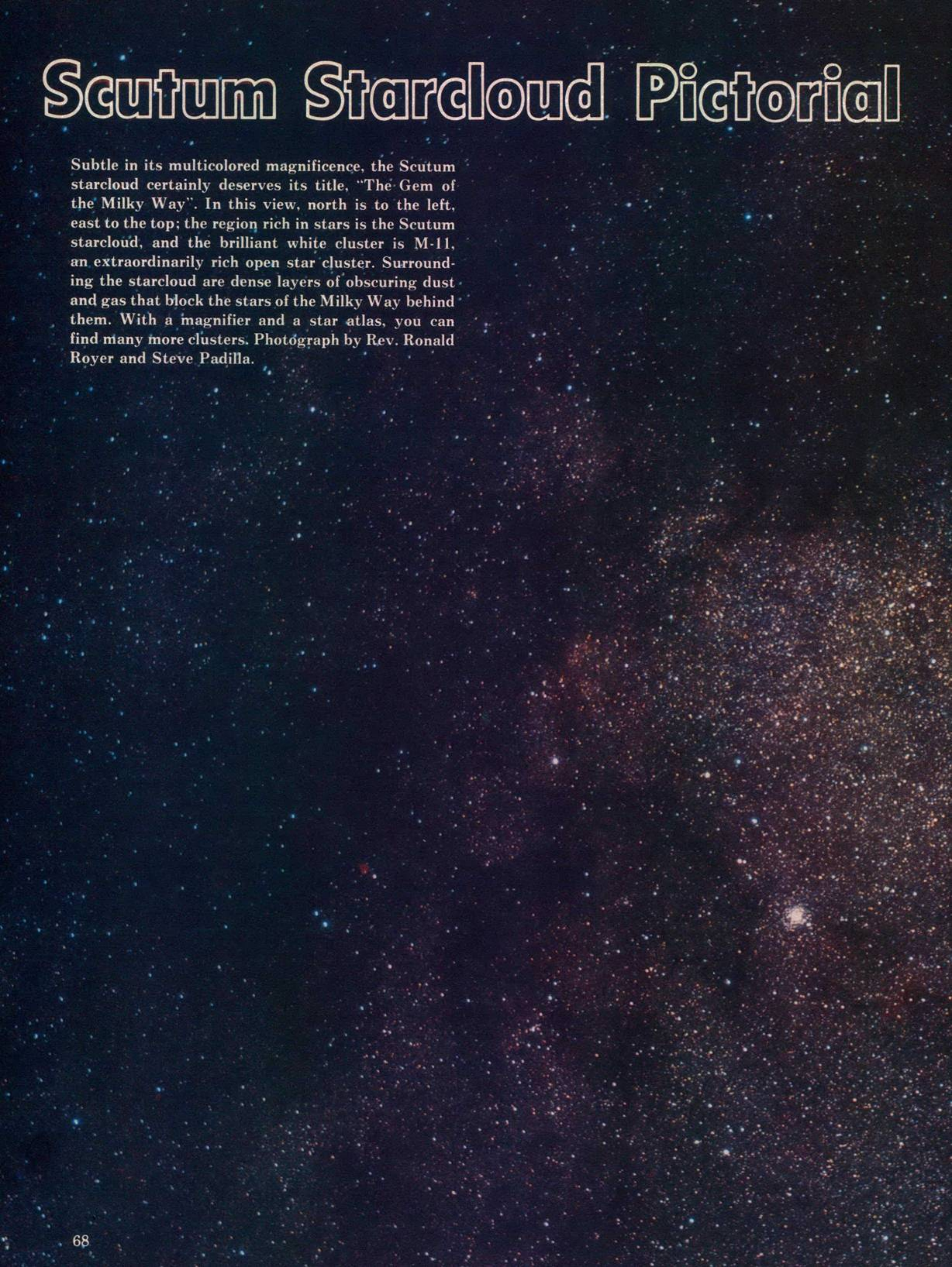
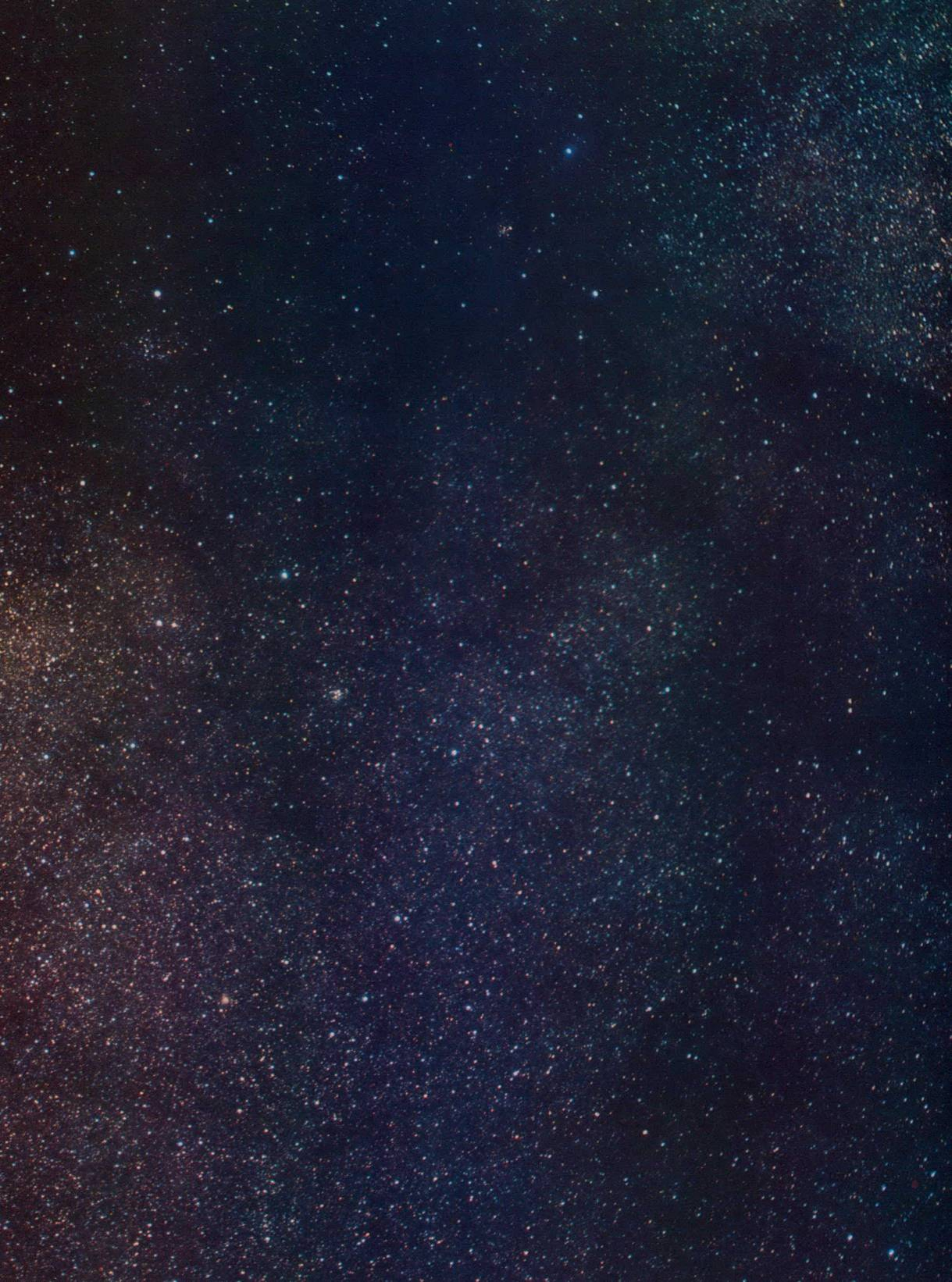
Scutum Starcloud Pictorial



Subtle in its multicolored magnificence, the Scutum starcloud certainly deserves its title, "The Gem of the Milky Way". In this view, north is to the left, east to the top; the region rich in stars is the Scutum starcloud, and the brilliant white cluster is M-11, an extraordinarily rich open star cluster. Surrounding the starcloud are dense layers of obscuring dust and gas that block the stars of the Milky Way behind them. With a magnifier and a star atlas, you can find many more clusters. Photograph by Rev. Ronald Royer and Steve Padilla.



PUBLISHER'S MEMO

Summer greetings ASTRONOMY readers, one and all. We trust your July weather isn't as swelteringly hot as Milwaukee's winter was cold! Matter of fact, may you have 31 balmy, clear nights of 10 rated seeing conditions (see Sky Almanac for explanation in this issue).

ASTRONOMY magazine is growing bigger and bigger every day (which would seem to mean that we're doing something very right). Just as Isaac Newton stated with his third law of motion, "For every action there is an equal or opposite reaction."

That has been the case here at ASTRONOMY, because as circulation increased demanding more employees to provide you the best magazine and service possible, I found myself wearing many more hats than I could possibly handle and still do the creative things I enjoy most as publisher and editorial director.

Consequently, I found it necessary to pass a few of these hats on to a brand new employee. On Feb. 1 this year, I hired Robert Maas as president of AstroMedia Corp. In this capacity Bob manages the mountain of day-to-day business details and financial affairs of AstroMedia Corp. and ASTRONOMY magazine, allowing me and other key ASTRONOMY employees more time to concentrate on the creative areas we enjoy most and do best.

What are some of Bob's statistics? He's 6'1-1/2" tall, has sandy brown hair, blue eyes . . . and for the 7-1/2 percent feminine minority among our readers . . . he's available!

Bob is our oldest employee, but you should see him keep us hopping — even me! He's a real powerhouse, with 14 years experience as a certified public accountant and executive management consultant, and he can make even the meanest computer behave!

With regard to other affairs of state, Feb. 1 I also elevated Penny Oldenburger to the position of assistant editorial director, in addition to her continuing duties as managing editor of ASTRONOMY magazine and AstroMedia Corp. vice president.

It has been "firmly" requested that I report to you we have acquired a slightly wounded staff artist. Mark Peternostro broke his arm while executing a semifancy — though not too graceful and definitely uncoordinated — loop de loop with his skateboard!! If the truth be known, he actually fell off the thing (sort of like a college teacher of mine who broke his leg falling up the stairs). Anyway send Mark your tears and sympathy. Besides, with looks like his, who needs coordination?

One final note on we Astro-people: Between Mary Jane Lamers (Astro-News Editor) and myself, we have lost a total combined weight of 70 pounds since January. For the 92-1/2 percent masculine majority out there, I've nicknamed her Astro-vamp . . . and she's available.

Speaking of arms, Peter Trabbold bit his nails down to the crazy bone waiting for his month overdue baby to arrive. Now that ASTRONOMY's first Astro-baby has finally gotten here, both parents and Astro-child are doing fine.

Lest you think things get a bit slapstick around here on occasion — they do . . . seldom a dull moment . . . we sure have a lot of fun though.

Getting briefly serious, this month's and next month's Publisher's Memo, as well as our new set of eight poster size art reprints, are being brought to you through the greater availability of time I have now that Bob and Penny are wearing a few of my hats. This further means that my Publisher's Memo (supposedly a monthly installment) will no longer be an infrequent semi-annual state of the union address . . . we hope.

Well folks, peace till next month, when we continue our saga of . . . .

Sincerely,

Stephen A. Walther

Stephen A. Walther
Publisher

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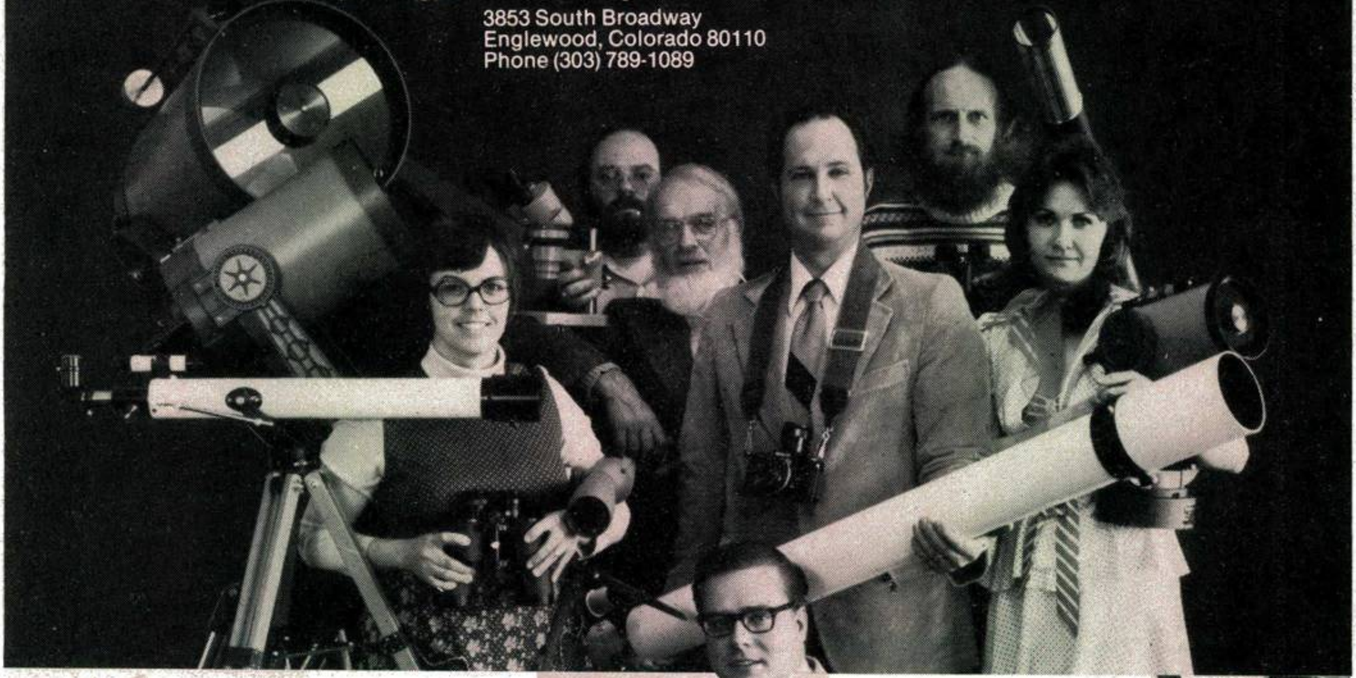

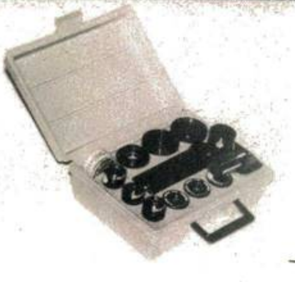

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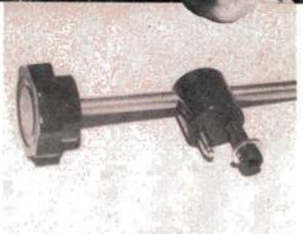

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STAR DOME

July

by
James Mullaney and Henry J. Phillips

If you face south any July evening, you can see the claws of Scorpius the scorpion stretching above the horizon. Described by astronomer Robert F. Baker as "the most formidable of the constellations", Scorpius is also one of the very brightest. Besides the red first magnitude star Antares, Scorpius contains five second magnitude stars and no less than eight third magnitude stars! Located in one of the brightest reaches of the Milky Way, Scorpius is a magnificent group of stars — and the farther south you see it from, the higher it rises in the sky and the more glorious it appears. Its scorpion shape is unmistakable: Its claws reach toward Libra to the west; its body curls beneath Ophiuchus, and its raised sting glows near the center of the summer Milky Way.

Antares marks the scorpion's heart. Its distinct red color gave this star its name; the word is Greek for "rival of Mars". Antares is a red supergiant star so large that if it were to replace the sun at the center of the solar system, the orbits of all the planets out to Mars would be beneath its surface. Antares ranks 16th of all the stars in brightness.

Only slightly less bright is Shaula (Lambda Scorpii), the brighter of a very close pair of stars that mark the sting in the scorpion's tail. Its dimmer companion's name is Lesuth; both titles are from alternate Arabian words for "sting". Shaula just misses being a first magnitude star (it's magnitude 1.60), but it nevertheless is one of the sky's 25 brightest.

Scorpius' other second magnitude stars include Dschubba (Delta Scorpii), the brightest star in the scorpion's upraised claws, with a magnitude of 2.34; Epsilon Scorpii (magnitude 2.28), southeast of Antares in the scorpion's body, a star that appears to have been unnamed except by the Chinese who called it and its neighbors Wei; Sargas (Theta Scorpii), directly south of Shaula, shining at magnitude 1.86, and Girtab (Kappa Scorpii), slightly to the left of a line between Shaula and Sargas, with a magnitude of 2.39.

Scorpius has so many telescopic showpieces that an observer can lose himself in its wonders for many successive evenings. Star Dome therefore presents an extended Close-Up section this month to introduce a few of these many marvels.

Close-Up

Scorpius Region

The splendid zodiacal figure of Scorpius houses a brilliant portion of the summer Milky Way and contains such a multitude of riches that our Table of Selected Objects might well be extended indefinitely. Therefore, we present only the very best of this constellation's many showpieces for visual observers, and provide detailed descriptions of every table entry this month.

From the latitude of Great Britain, Webb introduced Scorpius as follows: "A fine constellation, little noticed by casual star-gazers from its low altitude and short continuance above the horizon, with the additional disadvantage of its culminating during the brief summer's night."

In contrast, Barns' assessment from his site in southern California was "the most commanding of the summer constellations with burning Antares at its heart." Even from lower latitudes, this month's region is best explored when it is on or near the meridian, at its highest in the sky. Inevitable summer horizon haze will often obscure its densest star fields — those south of -30 degrees declination.

The Milky Way in Scorpius is a binocular and RFT user's delight, offering glories simply too numerous to mention here. All of the clusters in this month's table are within easy reach of such instruments, as well as many pairs and combinations of stars, ghostly nebulous regions and dark obscuring "vacancies" in the fabric of the sky. We highly recommend a session of leisurely sweeping along the "Great White Way" through Scorpius on the next dark clear night.

Antares [Alpha (α) Scorpii]

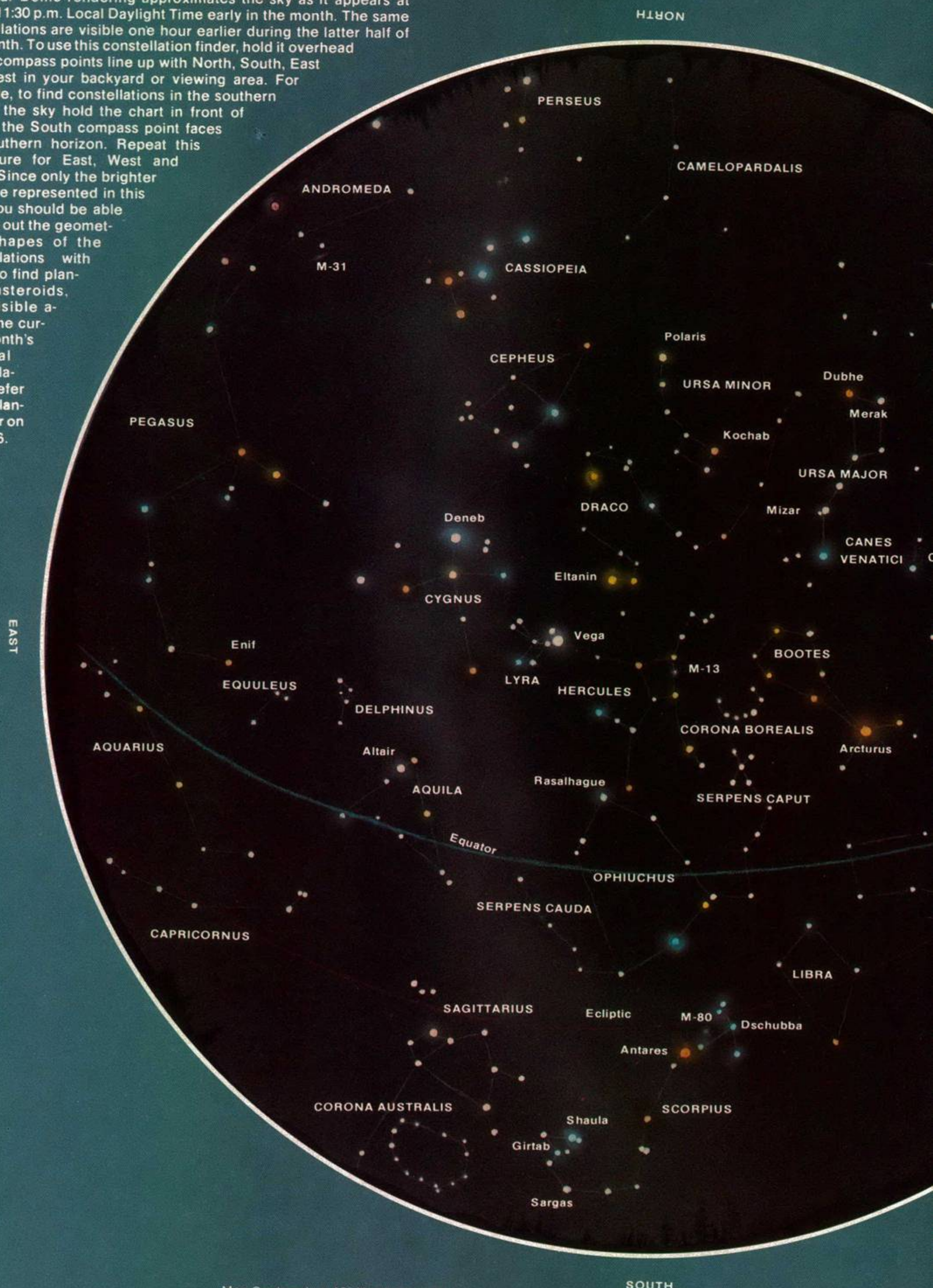
Fiery red Antares — the famed "rival of Mars" — blazes in splendor as we face the southern meridian on warm July evenings. This lovely first magnitude gem is a giant among giants as stars go: Its colossal orb measures some 370,000,000 miles in diameter (as compared to our sun's size of less than 1,000,000 miles). Like most supergiants, Antares slowly pulsates, varying both in size and brightness. Its magnitude ranges from 0.9 to 1.8 over a semiregular period of several years, and its intense hue has commanded attention through the centuries.

Antares is perhaps best known to today's observers as a spectacular telescopic double star, for it is attended by a vivid emerald green companion sun at a distance of just three seconds of arc. This object's exact brightness appears uncertain; depending on the source consulted, it is given as anywhere from fifth to seventh magnitude. The sixth magnitude value in our table is a mean of these figures, and matches the visual impression closely.

Nearly all observers, both past and present, agree in calling the primary red (or deep orange), and the companion an unmistakable green in tint. Green is relatively rare among star colors, but Webb tells us that Dawes "noticed a curious proof of its independent, not contrasted green light, when it emerged, in 1856, from behind the dark limb of the moon" before its overpowering neighbor, during a lunar occultation.

Other observers, including Smyth, have reported a blue color for the small star — but Smyth's observations, at least, indicate that he was prone to seeing that color. The actual spectral types of the two suns are M1 and B4, respectively.

This Star Dome rendering approximates the sky as it appears at about 11:30 p.m. Local Daylight Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 36.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CAPRICORNUS
LIBRA
SAGITTARIUS
Ecliptic
M-80
Dschubba
Antares
CORONA AUSTRALIS
SCORPIUS
Shaula
Girtab
Sargas
SOUTH

Map Centered on 43° North Latitude

LYNX
LEO MINOR
LEO
Caroli
COMA BERENICES
Denebola
WEST
VIRGO
Spica
CORVUS
HYDRA

Map by Adolf Schaller

As usual, Webb left us with the most telling description of Antares: "A grand telescopic object. Its tint, however, is not uniform; to me the disk appears yellow, with flashes of deep crimson alternating with a less proportion of fine green, the latter mixture perhaps accounted for by the seventh magnitude star near enough to be usually involved in the flaming rays of the principal, forming an atmospheric, rather than optical test."

Check this observation (made with a 3.7 inch refractor) against the view in your own telescope. Even if not clearly resolved, Antares will often show a distinct greenish flare to one side of its image (near position angle 275 degrees), hinting at the presence of the companion. Barns recorded this duo as "fire-bright prodigy . . . vivid emerald comes" through his 10 inch reflector.

As to the telescopic aperture required to split this contrasting pair, observers' opinions differ greatly. One modern stargazer states that he needs at least 10 inches, but Webb told of its having been achieved with less than three inches. Proctor claimed a glass larger than four inches was necesssary. Perhaps Muirden gave the best answer: "Notoriously difficult when Antares is low in the sky, but easily seen with a three inch when high. It is easier in strong twilight or moonlight than against a dark sky, when the primary's glare is accentuated." Implicit in this description is the importance of good seeing (image steadiness) for viewing the companion. On a tranquil night, the green star can be glimpsed without difficulty in four to six inch telescopes. Here, too, the training of the observer's eye is a factor to be considered.

Our drawing shows the view in a modern eight inch catadioptric telescope, at 200 power. As this rendering hints, under good atmospheric conditions Antares may well be the finest of all double stars for large amateur instruments

The companion appears relatively fixed in position near (or possibly within) the tenuous outer atmosphere of the primary, showing little change. Although generally considered to be a common proper motion (CPM) pair, the two suns are probably in slow orbital motion about each other, and a period in excess of 850 years has been computed.

This superb object lies some 520 light-years from us, beautifully projected against the fringes of the Milky Way.

Beta (β) Scorpii

In case poor seeing prevents a good view of Antares, you can turn to the bright double star Beta Scorpii, situated eight degrees northwest of the Martian rival. Even in the smallest of telescopes, this is a lovely object — as shown in our drawing with a 2.4 inch refractor at 35 power.

Beta is made up of third and fifth magnitude blue-white suns an easy 14 seconds apart. There is also a very difficult 10th magnitude companion less than one second away from the primary, as well as a close unresolved spectroscopic member with a seven day period. Therefore, although we list it as a double star, it is actually a multiple system like its neighbors Nu and Xi, described below. (There seems to be a clustering of multiple stars in this area!)

Beta Scorpii may remind you of the famous double star Mizar in the Big Dipper's handle, which it resembles to some extent. Most observers see both the primary and its companion as bluish white in tint, but other colors have been reported. Among them are white and blue, white and grayish, both white, green and blue, and even yellow and green or ashy green. Smyth gave "pale or yellow white, lilac", and Webb questioningly said it was "pale yellow, greenish".

This object appears in at least one classic listing under "finest white double stars", yet Barns called the pair "intense, colorful". Olcott remarked upon their "fine contrast", though he may have been referring to their magnitude rather than their color difference. The best way to settle the issue is to look for yourself. What heavenly hues do you see here with your scope?

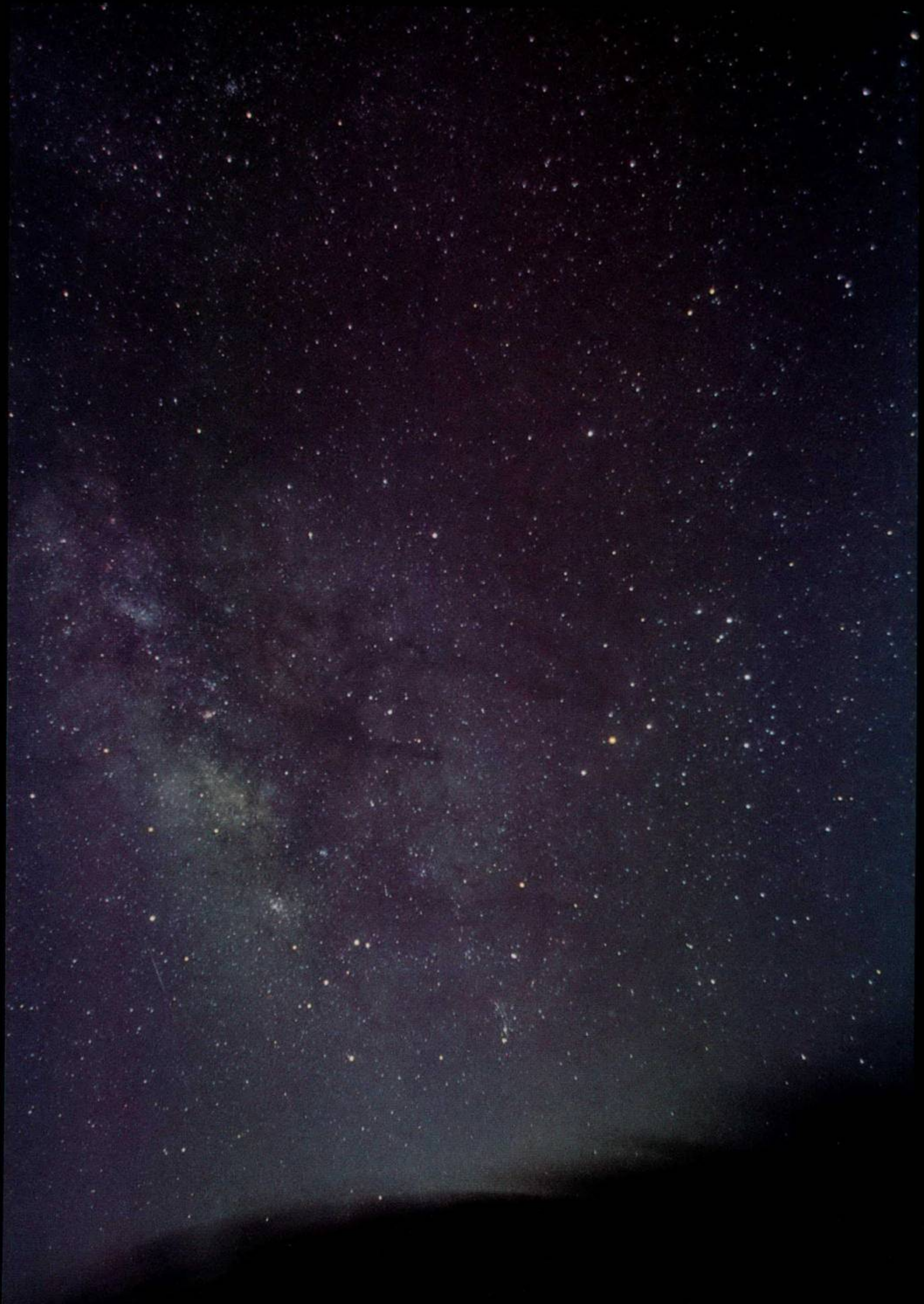
Beta Scorpii is a fine object to show visitors at the eyepiece. While they are viewing it, you might like to mention that this neat stellar duo is 650 light-years away — more than seven times that of its famous twin, Mizar.

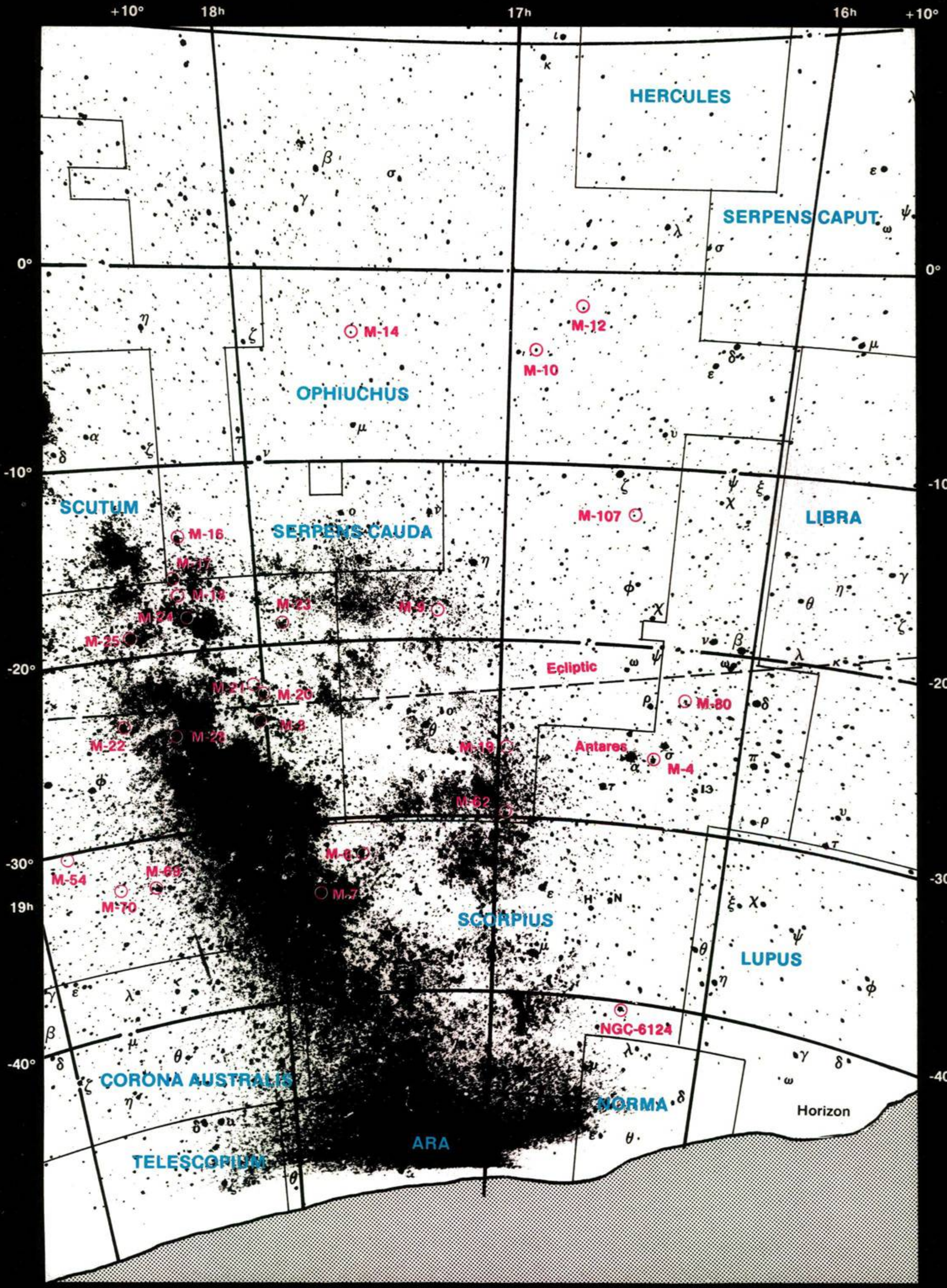
Nu (ν) Scorpii

We next examine a relatively unknown "copy" of Epsilon (ε) Lyrae, the noted "double-double" star. This is Nu Scorpii, located just 1-1/2 degrees half northeast of Beta. Although it appears to be a simple double star through binoculars and finders, it is in reality a telescopic quadruple system.

Nu consists of two tight pairs of stars, separated by 42 seconds of arc in a roughly north-south direction. The brighter pair, made up of 4.4 and 6.4 magnitude stars, has a separation of about one second of arc. The fainter pair has stars of 6.8 and 7.8 magnitudes, and is twice as wide at two seconds separation.

A three inch refractor will usually show only a wide double, but in good seeing at high power, you can split the wider pair and elongate the other with a small instrument. A six inch reflector at 250 power reveals all four stars




+10°
18h
17h
16h
+10°
HERCULES
SERPENS CAPUT
0°
0°
M-14
M-12
M-10
OPHIUCHUS
-10°
-10°
SCUTUM
M-16
SERPENS CAUDA
M-107
LIBRA
M-17
M-18
M-23
M-9
M-24
M-25
-20°
Ecliptic
-20°
M-21
M-20
M-80
M-8
M-22
M-28
M-19
Antares
M-4
M-62
-30°
M-6
-30°
M-54
M-69
M-70
M-7
19h
SCORPIUS
LUPUS
NGC-6124
-40°
-40°
CORONA AUSTRALIS
NORMA
Horizon
ARA
TELESCOPIUM
19h
18h
17h
16h

Photograph by Brad Wallis
Map by Henry J. Phillips

neatly resolved, as seen in our drawing. As telescopic aperture increases, Nu becomes ever more attractive; it is sometimes called the most beautiful quadruple star in the sky through large instruments.

While fainter and more difficult to resolve than Epsilon Lyrae, this object is also much more colorful. The brighter pair are both yellow and the fainter one both orange, as our sketch shows. Most viewers agree with this yellow-orange combination, but Smyth saw them pale yellow and dusky and Muirden called the fainter pair grayish. Nu is attractive enough to have rated a place in Pickering's famous roster of the sky's 60 finest objects. Yet, many observers have never seen it. Have you?

Xi (ξ) Scorpii

Yet another of this region's fine stellar showpieces can be found 8-1/2 degrees directly north of Beta. This is Xi Scorpii, a multiple system made up of five individual suns neatly grouped together.

The scene this time consists of a triple and a double lying in the same eyepiece field some 280 seconds apart. Technically, Xi itself is only the trio — 4.9, 4.9 and 7.2 magnitude stars at separations of one and seven seconds. The duo, Struve 1999, is made up of 7.5 and 8.0 magnitude stars about 12 seconds distant from each other. Orbital motion is evident in both of these systems — the fifth magnitude pair has a relatively short period of just 46 years. All five suns drift through space together as one vast family.

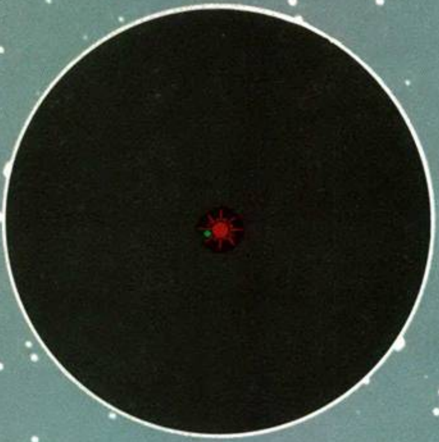
In three and four inch telescopes at magnification under 100, this object appears as yet another double-double — and it's much easier to resolve than Nu Scorpii. However, at 150 power or more in good seeing, the close fifth magnitude pair becomes resolved and the illusion is lost.

The colors in this unusual system seem to be yellow, white and purple as shown in our drawing. Smyth gave Xi's tints as bright white and pale yellow, with the third star gray. Dawes found the bright pair as both yellow, and Webb logged the Struve duo as white and yellow white, noting that some observers had reported blue or purple casts here. Confirming such subtle differences in color is part of the great fascination of double star observing.

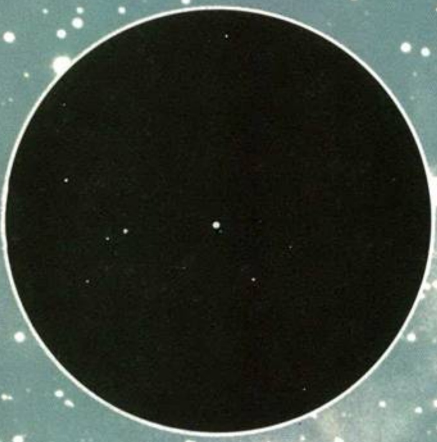
Webb called the Xi-Struve 1999 stellar conglomerate a "beautiful field" and Pickering added it to his listing. Strangely, some observers like Barns noted only the bright close pair, without commenting on the other members of this system.

M-4

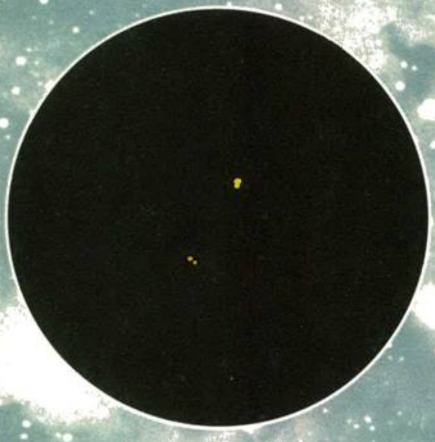
Turning our attention now to some of this region's fine star clusters, we examine the first of two Messier globulars within handy reach of Antares. M-4, located just over one degree west



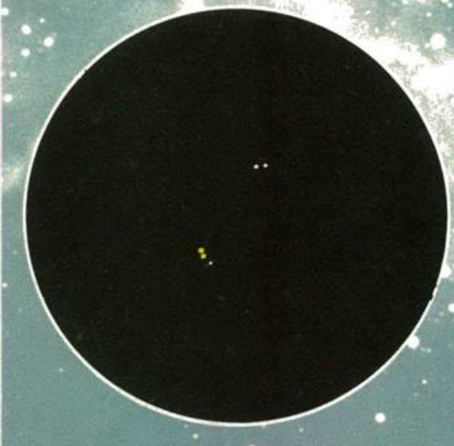
Antares N 200x



Beta Scorpii N 35x



Nu Scorpii N 250x



Xi Scorpii N 150x

Top to bottom: Antares is not only one of the brightest and reddest stars in the sky, but the telescope also reveals it to be double. Its faint green companion is well seen through large instruments. The drawing shows the view through an eight inch Schmidt-Cassegrain at 200 power; the field of view is about 15 seconds of arc. Beta Scorpii is a wide double, easily separated with a 2.4 inch refractor at 35 power, as this next drawing shows. The field of view is 90 seconds of arc. Below, the two pairs of stars that comprise Nu Scorpii are of contrasting orange and yellow colors. A six inch reflector at 250 power was used for this drawing. The field of view is about 10 seconds of arc. At bottom, Xi Scorpii is another fascinating multiple system; each star is subtly different in color from its companions. The field of view is about 20 seconds of arc in this drawing, showing the view through a four inch reflector at 150 power. Drawings by James Mullaney.

Selected Objects — Scorpius Region

Object	Type	Mag.	Size/Sep.	R.A. (1950)	Dec.
*ξ (Xi)+	★5	4.9,4.9,7.2 7.5,8.0	1",7" 12"	16^h02^m	-11° 14'
*β (Beta)	★2	2.9,5.1	14"	16^h02^m	-19° 40'
*ν (Nu):	★4	4.4,6.4 6.8,7.8	1" 2"	16^h09^m	-19° 20'
*M-80	GC	7.7	3'	16^h14^m	-22° 52'
*M-4	GC	6.4	14'	16^h21^m	-26° 24'
*NGC-6124	OC	6.3	25'	16^h22^m	-40° 35'
*Antares	★2	0.9,6.0	3"	16^h26^m	-26° 19'
*M-6	OC	5.3	25'	17^h37^m	-32° 11'
*M-7	OC	3.2	60'	17^h51^m	-34° 48'

*Detailed in Close-Up
+Pairs separated by 280"
:Pairs separated by 42"

★2 = Double Star
★4,5 = Multiple Star
OC = Open Cluster
GC = Globular Cluster
Mag. = Magnitude
Sep. = Separation

of the great star, is a loose concentration of relatively dim stars. It shines at magnitude 6.4 and measures at least 14 minutes of arc in size. This large swarm of suns appears as a granular disk in three inch telescopes. A good four incher can break it into individual pinpoints of light, and M-4 is resolved into its center in six inch and larger instruments on a good night. Reflectors of 10 and 12 inches aperture show many apparent chains of stars and give the impression of dark lanes crossing over the cluster. They also reveal M-4's brightest members to be reddish in hue.

Webb described this object as "large, rather dim, resolvable, followed by a vacant starless space"; Barns saw it as a "dim but interesting star-cloud". The Messier authority Holyoke considers this a much finer globular cluster than those in Ophiuchus, mentioning that it doesn't look as bright as it really is because of its great size (large surface area spreads its light).

M-4's loose concentration of stars gives some the impression of a faint but rich open cluster rather than a globular. Its distance is also unusually close for a globular — a relatively nearby 7,500 light-years! M-4 is, in fact, the nearest of all the prominent globulars.

On a dark summer's night without interfering moonlight, with both good seeing and transparency, this swarm of stars is truly an awesome sight in larger instruments.

M-80

Presenting a striking contrast to M-4 is the nearby globular cluster M-80. Positioned midway between Antares and Beta Scorpii, this cluster is easily swept up in a small telescope at low power.

Both fainter and much smaller in apparent size than its neighbor, M-80 shines at magnitude 7.7 and measures only three minutes in diameter. While the stars in M-4 are loosely packed, those in M-80 are so highly compressed that this object reminds some observers of the head of a comet.

Probably the finest classic description of this globular was made by Sir William Herschel, who considered it "the richest and most condensed mass of stars which the firmament can offer to the contemplation of astronomers". While this impression was certainly valid with Herschel's large metal-mirrored reflectors, it will likely leave you sorely disappointed unless you are using a fairly large scope (12 inches or more aperture).

A better indication of what small instruments show was given by Webb: "Like a comet; in a beautiful field . . . on the western edge of a vast starless opening four degrees broad; in which, however, I found many minute stars. Nearly central is the strange variable T, which, 1860, between May 18 and 21, had blazed out to seventh magnitude extinguishing apparently the cluster, had almost faded by June 16, and has never distinctly reappeared. In field, following a little north, are the two variables R and S; the whole in singular juxtaposition."

R and S Scorpii are both dim, long period variables that are fainter than ninth magnitude at their brightest. Scorpii is today somewhere below 12th magnitude and carries the designation Nova 1860. Some astronomers suspect that T may actually have been a supernova, considering its apparent luster on those long-ago nights and the vast gulf of space between us and the clusters — a distance of 36,000 light-years. Like certain other novae in the past, T Scorpii may be recurrent and could someday rise to glory again. The observer should therefore be alert to its possible reappearance whenever examining this cluster.

Barns called M-80 a "noble cluster", and the NGC lists it as "remarkable — very much so". Holyoke said it looks brighter than it actually is due to its small size and great concentration, and that it may impress the observer as *brighter* than M-4 — which it is not!

Even in small telescopes, M-80 is a fascinating object — its mysterious blazing core luring us to imagine the wonders it holds swallowed in the darkness of night.

M-6 and M-7

Two stunning Messier open clusters —often passed over by observers because of their southerly declinations — are found near the scorpion's sting. These are M-6 and M-7, both visible to the unaided eye on a dark night and superb sights even in binoculars.

At a declination of nearly -35 degrees, M-7 is the farthest south of all the Messier entries. It is situated about four degrees northeast of Upsilon (υ) and Lambda (λ) Scorpii. M-6 lies about four degrees northwest of M-7.

M-6 has an integrated (combined) magnitude of 5.3 and is 25 minutes in size, while M-7 shines at 3.2 magnitude and spans 60 minutes — twice the apparent diameter of the full moon! Both contain at least 50 stars and are considered "intermediate-rich" in concentration as open clusters go.

These clusters need low power and a wide field to be appreciated. They are magnificent in four inch richest field telescopes at 15 power and with a 3-1/2 degree field, but larger conventional telescopes with their reduced fields of view lessen the overall impact — though the clusters are still impressive. And they are downright disappointing in big observatory telescopes! As is the case with many of the brighter double stars, most open clusters look much better in backyard instruments than they do in our largest telescopes.

Most of those observers who have bothered to look at them consider these two clusters among the finest of all deep sky objects. Both are large, bright and scattered, with star streams radiating outward. M-6 has been described as "like a butterfly with open wings" and also as an "open flower". Pickering included M-7 in his roster under coarse clusters and stated that "many of the stars are arranged in lines approximately at right angles."

Neither Webb nor Barns mentioned these clusters in their classic works, since their surveys did not go lower than about -30 degrees declination. Light and other forms of atmospheric pollution impose a similar cutoff at low altitudes for many observers today. Still, these objects are certainly worth the effort to locate — either by watching diligently for an unusually clear night, or temporarily moving to a darker site in order to see them.

M-6 lies about 1,800 light-years from us, while M-7 is nearer by some 600 light-years. Their scattered jewels splash vividly across the Milky Way background in an unforgettable cosmic pageant. They are "musts" for all star lovers — a sight for all ages.

NGC-6124

We conclude our survey of this month's memorable region with an open cluster that is typical of the many low lying wonders to be found in southern Scorpius. This is NGC-6124, located 13 degrees due south of Antares at a declination of -40-1/2 degrees.

Glowing at magnitude 6.3, this cluster contains more than 120 stars within its 25 minute diameter, making it much richer than either M-6 or M-7. It shows up well in medium size instruments on a good night even with horizon haze, and is a real showpiece from the southern hemisphere. Yet it is only one of a host of such objects that lurk unsuspected throughout this region of the sky. Here, the sense of awe and adventure runs high.

The overall visual aspect of this month's region — from flashing Antares to the glimmer of the Milky Way beyond — has a decided "busy" look to it. Exploring its farflung treasures is an exhilarating experience — one that gives flight to the spirit and certainly adds zest to life. As Olcott so well expressed it, the telescope "will never cease to offer you many hours of keen enjoyment, and a source of pleasure in the contemplation of the beauties of the firmament that will enrich and ennoble your life".

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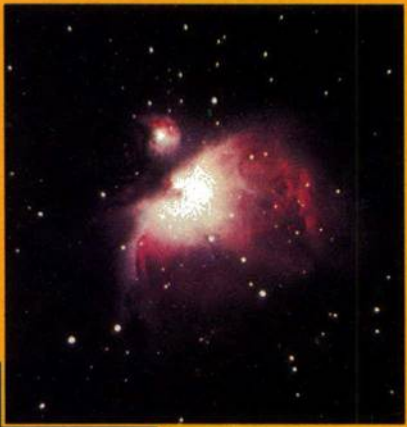

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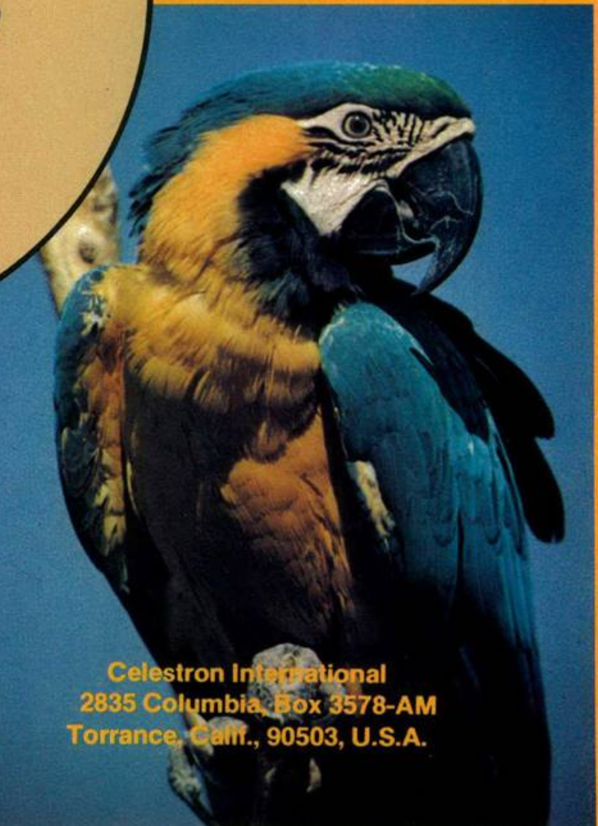

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